A LIQUID CRYSTAL DEVICE AND A METHOD FOR MANUFACTURING THEREOF

Technical field

The present invention generally relates to the field of liquid crystals. More specifically, the present invention relates to a liquid crystal device comprising a liquid crystal bulk layer presenting a surface-director at a bulk surface thereof, and a surface-director alignment layer arranged to interact with the bulk layer at said bulk surface for facilitating the obtaining of a preferred orientation of the surface-director of the bulk layer.

The invention also relates to a method for manufacturing a liquid crystal device and a method of controlling a liquid crystal bulk layer.

Technical background

Liquid crystals, widely used at present as electro-optical media in display devices, are organic materials with anisotropic physical properties. Liquid crystal molecules are generally long rod-like molecules, so-called calamitic molecules, which have the ability to align along their long axis in a certain preferred direction (orientation). The average direction of the molecules is specified by a vector quantity and is called director.

It may be noted, however, that there also exist liquid crystal molecules that are disc-like, so-called discotic molecules.

The operation of the liquid crystal displays is based on the changes of the optical characteristics, such as light transparency, light absorption at different wavelengths, light scattering, birefringence, optical activity, circular dichroism, etc, of the liquid crystal in the display caused by an applied electric field (direct coupling).

One of the basic operational principle of liquid crystal displays and devices is the switching of the orientation of the liquid crystal molecules by an applied electric field that couples to the dielectric anisotropy of the liquid crystal (dielectric coupling). Such a coupling gives rise to an electro-optic response quadratic with the applied electric field, i.e. independent of the field polarity. There exist a number of different types of LCDs (liquid crystal displays) whose operation is based on dielectric coupling, especially dynamic scattering displays, displays using deformation of homeotropically aligned nematic liquid crystal, Schadt-Helfrich twisted nematic (TN) displays, super twisted nematic (STN) displays, in-plane switching (IPS) nematic displays.

For modern applications, a LCD should possess several important characteristics, such as a high contrast and brightness, a low power consumption, a low working voltage, short rise (switching) and decay (relaxation) times, a low viewing angle dependence of the contrast, a grey scale or bistability, etc. The LCD should be cheap, easy to produce and to work with. None of the prior-art LCDs is optimised concerning all the important characteristics.

A nematic liquid crystal material exhibits the simplest liquid crystalline structure , i.e. an anisotropic liquid. In a nematic material, the liquid crystal molecules are aligned toward a particular direction in space, but the centre of mass of molecules is not ordered.

In most of the conventional nematic liquid crystal displays, operating on the basis of the dielectric coupling, the electric field is applied normally to the liquid crystal bulk layer (i.e. normally to the confining substrates) and the liquid crystal bulk molecules are switched by the electric field in a plane perpendicular to the confining substrate surfaces (so-called out-of-plane switching). These displays are usually slow, and

nearly all suffer from non-satisfactory angular dependence of the contrast.

There is also another type of LCDs with in-plane switching, in which the electric field is applied along the liquid crystal bulk layer (i.e. in parallel with the confining substrates) and the liquid crystal bulk molecules are switched in a plane in parallel with the confining substrate surfaces. These displays exhibit a very small angular dependence of the image contrast but the resolution and the switching time are not satisfactory.

In the liquid crystal displays discussed above, the desired initial alignment of the liquid crystal layer in the absence of an external field, such as an electric field, is generally achieved by appropriate surface treatment of the confining solid substrate surfaces, such as by applying a so-called (surface-director) alignment layer (also called orientation layer) on the confining substrate surfaces facing said liquid crystal bulk. The initial liquid crystal alignment is defined by solid surface/liquid crystal interactions. The orientation of the liquid crystal molecules adjacent the confining surface is transferred to the liquid crystal molecules in the bulk via elastic forces, thus imposing essentially the same alignment to all liquid crystal bulk molecules.

The director of the liquid crystal molecules near the confining substrate surfaces (herein also called surface-director) is constrained to point in a certain direction, such as perpendicular to (also referred to as homeotropic or vertical) or in parallel with (also referred to as planar) the confining substrate surfaces. The type of alignment in liquid crystal displays operating on the coupling between liquid crystal dielectric anisotropy and applied electric field is chosen in accordance with the sign of the dielectric anisotropy, the direction of the applied electric field and the desired type of switching mode (in-plane or out-of plane).

In out-of-plane switching liquid crystal cells employing a liquid crystal bulk having a negative dielectric anisotropy, it is important to uniformly orient the director of the liquid crystal bulk molecules (in the field-off state) vertically to the substrate surfaces (so-called homeotropic alignment).

An example of a method for establishing a homeotropic alignment comprises coating the confining substrate surfaces with a surfactant, such as lecithin or hexadecyltrimethyl ammonium bromide. The coated substrate surfaces is then also preferably rubbed in a predetermined direction, so that the field-induced planar alignment of the liquid crystal molecules will be oriented in the predetermined rubbing direction. This method may give good results in laboratory studies, but has never found industrial acceptance due to that long term stability is not obtained as the alignment layer is slowly dissolved in the bulk liquid crystal (J. Cognard, Mol. Cryst. Liq. Cryst., Suppl. Ser., 1982, 1, 1).

In out-of-plane switching liquid crystal cells employing a liquid crystal bulk having a positive dielectric anisotropy, it is important to uniformly orient the director of the liquid crystal bulk molecules (in the field-off state) in parallel with the substrate surfaces (so-called planar alignment). For twisted nematic liquid crystal cells, it is also important to orient the liquid crystal bulk molecules at a certain inclined orientation angle (pre-tilt angle) to the substrate.

Known methods for establishing planar alignment is, for instance, the inorganic film vapour deposition method and the organic film rubbing method.

In the inorganic film vapour deposition method, an inorganic film is formed on a substrate surface by vapour-deposition of an inorganic substance, such as silicon oxide, obliquely to the confining substrate so that the liquid crystal molecules are oriented by the inorganic film in a certain direction depending on the inor-

ganic material and evaporation conditions. Since the production cost is high, and the method thus is not suitable for large-scale production, this method is practically not used. According to the organic film rubbing method, an organic coating of, for instance, polyvinyl alcohol, polyoxyethylene, polyamide or polyimide, is formed on a substrate surface. The organic coating is thereafter rubbed in a predetermined direction using a cloth of e.g. cotton, nylon or polyester, so that the liquid crystal molecules in contact with the layer will be oriented in the rubbing direction.

Polyvinyl alcohols (PVA) are commercially rarely used as alignment layers since these polymers are hydrophilic, hygroscopic polymers that may adsorb moisture adversely affecting the molecular orientation of the polymer and thus the liquid crystal device performance. In addition, PVA may attract ions which also impairs the liquid crystal device performance.

Also polyoxyethylenes may attract ions, thus resulting in impaired liquid crystal device performance.

Polyamides have a low solubility in most commonly accepted solvents. Therefore, polyamides are seldom used commercially in liquid crystal device manufacturing.

Polyimides are in most cases used as organic surface coating due to their comparatively advantageous characteristics, such as chemical stability, thermal stability, etc.

In in-plane switching liquid crystal cells employing a liquid crystal bulk having a positive or negative dielectric anisotropy, it is important to uniformly orient the director of the liquid crystal bulk molecules in parallel with the substrate surfaces. The aligning methods used in this case are similar to those used for out-of-plane switching of liquid crystal cells employing a liquid crystal bulk having a positive dielectric anisotropy.

In in-plane switching liquid crystal cells employing a liquid crystal bulk having a positive dielectric ani-

sotropy, the initial field-off planar alignment of the liquid crystal bulk molecules is perpendicular to the direction of the applied electric field.

In in-plane switching liquid crystal cells employing a liquid crystal bulk having a negative dielectric anisotropy, the initial planar alignment of the liquid crystal bulk molecules is along the direction of the applied electric field.

In all of the above disclosed methods of aligning the director of the liquid crystal bulk molecules near the confining substrates, a so-called (surface-director) alignment layer is generally applied on the confining substrate surfaces facing said liquid crystal bulk.

It may be noted, that in the prior art (e.g. in US 2002/0006480) alignment layers of materials having mesogenic groups in their structure have been described. This type of layers is primarily used to increase the interaction between the alignment layer and the (mesogenic) liquid crystal bulk layer in the field-off state, but the alignment layer is not described to be substantially affected by an applied electric field (i.e. it is not directly controllable by an electric field).

In the prior of art, there are in principal three different techniques for changing the optical performance of liquid crystals by accomplishing a new molecular orientation of the liquid crystals that differs from the initial alignment.

The first, most widely used technique for re-orientating the molecules is to apply an external electrical field over the entire bulk liquid crystal layer. Due to direct coupling between the electric field and some of the liquid crystal material parameters, such as dielectric anisotropy, the field will directly reorient the liquid crystal bulk molecules in a new direction if their initial alignment does not correspond to a minimum energy of interaction of the electric field with the liquid crystal bulk.

The second known technique for reorienting the molecules of a liquid crystal layer is to design one or both of the confining alignment surfaces as a photo-controlled "command surface". Such a photo-controlled command surface is capable, when subjected to, for instance, UV light, to change the direction of alignment imposed by the surface on the liquid crystal molecules in contact with the surface. The concept of "photo commanded surface" has been described by K. Ichimura in a number of papers overviewed in Chemical Reviews, 100, p.1847 (2000). More specifically, an azobenzene monolayer is deposited onto the inner substrate surface of a sandwich cell containing a nematic liquid crystal layer. The azobenzene molecules change their conformation from "*trans*" to "*cis*" under illumination with UV light. The azobenzene molecules are anchored laterally to the substrate surface by the aid of triethoxysilyl groups. The *trans*-isomer of azobenzene moieties imposes a homeotropic alignment of the nematic liquid crystal, whereas the *cis*-isomer gives a planar orientation of the liquid crystal molecules. Hence, the conformational changes of the molecules in the alignment layer caused by the UV illumination will result in a change of the alignment of the nematic liquid crystal molecules. The relaxation to the initial alignment is obtained by illuminating the sample with VIS-light or simply by heating it to the isotropic state.

The third known principle for re-orientating liquid crystal molecules involves the use of so-called Electrically Commanded Surfaces (ECS). This principle is described in the published International patent application No. WO 00/03288. The ECS principle is used to primarily control a ferroelectric liquid crystalline polymer layer. According to ECS principle, a separate thin ferroelectric liquid crystalline polymer layer is deposited on the inner surfaces of the substrates confining a liquid crystal bulk material in a conventional sandwich cell. The ferro-

electric liquid crystalline polymer layer acts as a dynamic surface alignment layer imposing a planar or substantially planar alignment on the adjacent liquid crystal bulk material. More specifically, when applying an external electric field across the cell - and thereby across the surface alignment layer - the molecules in the separate ferroelectric liquid crystalline polymer layer will switch. This molecular switching in the separate polymeric layer will, in its turn, be transmitted into the bulk volume via elastic forces at the boundary between the separate alignment layer and the bulk layer, thus resulting in a relatively fast in-plane switching of the bulk volume molecules mediated by the dynamic surface alignment layer. The ECS layer should be very thin (100-200 nm), and should preferably be oriented in bookshelf geometry, i.e. with smectic layers normal to the confining substrates. Furthermore, in order to keep the ECS layer and its operation intact, the material of ECS layer should be insoluble in the liquid crystal bulk material.

To optimise the performance of liquid crystal devices, it is desirable to decrease the total time period needed to switch and relax the liquid crystal bulk molecules in response to an applied external field. The total response time consists of a rise time (switching of the liquid crystal molecules to a field-induced orientation state) and a decay time (relaxation of the liquid crystal molecules to a field-off orientation state). In prior art liquid crystal devices, the rise time is generally shorter than the decay time, for instance the rise time may be about 1/3 of the total response time and the decay time may be about 2/3 of the total response time.

The decay time of a prior art out-of-plane switching nematic liquid crystal device is generally about 20-100 ms resulting in a low image quality, in particular for moving images. The problem of long decay times is more serious for liquid crystal devices having large display

areas, and in particular for out-of-plane switching liquid crystal devices.

A liquid crystal device having a long rise time, and thus long total response time, also provide a low image quality, in particular for moving images. The problem of long rise times is more serious for liquid crystal devices having large display areas, and in particular for in-plane switching liquid crystal devices. In-plane switching of the surface-director of the liquid crystal molecules is somewhat restrained, and thus slowed down, by the substrate surfaces. The rise time of prior art in-plane switching nematic liquid crystal devices is generally about 10-20 ms.

Fig 1 schematically shows the principle of a prior art out-of-plane switching liquid crystal device 1 including a liquid crystal bulk layer 2 having a negative dielectric anisotropy ($\Delta\varepsilon < 0$) between confining substrates 3. In the field-off state ($E = 0$), the liquid crystal bulk molecules are vertically aligned, via elastic forces, by a conventional surface-director alignment layer (not shown) applied on the confining substrate surfaces 3. When an external electric field is applied ($E \neq 0$) across the liquid crystal bulk layer 2 between electrodes 4 on the confining substrates 3, the liquid crystal molecules 2 are switched to a field-induced planar orientation. However, the liquid crystal molecules 2 located near the confining substrate surfaces 3 are not only affected by the applied electric field, but also by the surface-director alignment layer, which result in an elastic deformation D1 of the liquid crystal layer 2 near the substrate surfaces 3, as shown in Fig 1. After removal of the external field, the liquid crystal molecules 2 near the surface-director alignment layer relax to their initial field-off orientation, due to the solid surface/liquid crystal interactions. The relaxation of the liquid crystal molecules 2 in this region affects, via elastic forces, the orientation of the more remote

liquid crystal bulk molecules 2. Thus, the elastic deformation D1 that takes place in the liquid crystal layer 2 under an applied electric field disappears and the initial uniform field-off homeotropic alignment of the entire liquid crystal bulk layer 2 is finally restored. However, as mentioned above, the relaxation to field-off orientation is rather slow, thus resulting in a rather long decay time.

The same type of problem is illustrated for the prior art out-of-plane switching liquid crystal device 1′ shown in Fig 2, said device 1′ including a liquid crystal bulk layer 2′ having a positive dielectric anisotropy ($\Delta\varepsilon > 0$) between confining substrates 3′ coated with a conventional surface alignment layer (not shown). In the field-off state ($E = 0$), the liquid crystal bulk molecules 2′ exhibit a planar alignment. When an external electric field is applied ($E \neq 0$) across the bulk liquid crystal layer 2′ between electrodes 4′ on the confining substrates 3′, the liquid crystal molecules 2′ are switched to a field-induced vertical orientation. An elastic deformation D2 of the liquid crystal layer 2′ near the substrate surfaces 3′ is shown in Fig 2.

Fig 3 schematically shows a top view of a prior art in-plane switching liquid crystal device 1′′ including a liquid crystal bulk layer 2′′ having a positive dielectric anisotropy ($\Delta\varepsilon > 0$) between confining substrates 3′′ (only one substrate is shown). In the field-off state ($E = 0$), Fig 3a, the liquid crystal bulk molecules 2′′ exhibit a planar alignment in a first orientation direction obtained, via elastic forces, by a surface-director alignment layer (not shown) applied on the confining substrate surfaces 3′′. When an external electric field is applied ($E \neq 0$), Fig 3b, along the bulk liquid crystal layer 2′′ (i.e. in parallel with the confining substrates) between electrodes 4′′ placed as shown in Fig 3, the liquid crystal molecules 2′′ are switched in-plane to a field-induced second orientation direction along the

orientation of the electric field. However, the switching of the liquid crystal molecules 2'' will be restrained, as shown in Fig 3b, by the surface-director alignment layer, thus resulting in a rather long rise time.

The same reasoning applies to an in-plane switching liquid crystal device including a liquid crystal bulk layer having a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

Summary of the invention

In light of the above-mentioned drawback of the known liquid crystal displays, a general object of the present invention is to provide an improved liquid crystal device, an improved method for manufacturing a liquid crystal device, and an improved method of controlling a liquid crystal device. The invention is not directed to displays only, but is useful in many other liquid crystal devices.

According to a first aspect of the invention, there is provided a liquid crystal device comprising a liquid crystal bulk layer presenting a surface-director at a bulk surface thereof, and a surface-director alignment layer comprising side-chains arranged to interact with the bulk layer at said bulk surface for facilitating the obtaining of a preferred orientation of the surface-director of the bulk layer, wherein the orientation of the molecules of the liquid crystal bulk layer and the orientation of said side-chains of the surface-director alignment layer each is directly controllable by an electric field via dielectric coupling.

In a first embodiment of the device according to the invention, the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs. This device makes it possible to shorten the total response time by shortening the decay time, such as to below 20 ms, e.g. about 4-6 ms, and thus provide an improved image quality, in particular for moving images and large display devices. This effect is es-

pecially advantageous in out-of-plane switching liquid crystal devices.

In a second embodiment of the device according to the invention, the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of same sign. This device makes it possible to shorten the total response time by shortening the rise time, such as to below 10 ms, e.g. about 1-5 ms, and thus provide an improved image quality, in particular for moving images and large display devices. This effect is especially advantageous in in-plane switching liquid crystal devices.

In a third embodiment of the device according to the invention, the surface-director alignment layer comprises structural parts exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs. This device is believed to make it possible to shorten the total response time by shortening the rise time as well as the decay time.

According to a second aspect of the invention, there is provided a method for manufacturing a liquid crystal device comprising the steps of providing a surface-director alignment layer on an inner surface of at least one substrate, and sandwiching a liquid crystal bulk layer between two substrates, said liquid crystal bulk layer presenting a surface-director at a bulk surface thereof, and said surface-director alignment layer comprising side-chains arranged to interact with the bulk layer at said bulk surface for facilitating the obtaining of a preferred orientation of the surface-director of the bulk layer, wherein the orientation of the molecules of the liquid crystal bulk layer and the orientation of said side-chains of the surface-director alignment layer each is directly controllable by an electric field via dielectric coupling.

According to a third aspect of the invention, there is provided a method of controlling a liquid crystal bulk layer comprising the step of aligning a liquid crystal

bulk layer presenting a surface-director at a bulk surface thereof by use of a surface-director alignment layer comprising side-chains arranged to interact with the bulk layer at said bulk surface for facilitating the obtaining of a preferred orientation of the surface-director of the bulk layer, wherein the orientation of the molecules of the liquid crystal bulk layer and the orientation of said side-chains of the surface-director alignment layer each is directly controllable by an electric field via dielectric coupling.

Brief description of the drawings

Fig 1 schematically shows a prior art out-of-plane switching liquid crystal device exhibiting an initial vertical alignment of the liquid crystal bulk layer.

Fig 2 schematically shows a prior art out-of-plane switching liquid crystal device exhibiting an initial planar alignment of the liquid crystal bulk layer.

Fig 3 schematically shows a prior art in-plane switching liquid crystal device.

Fig 4 schematically shows an embodiment of an out-of-plane switching liquid crystal device according to the invention exhibiting an initial vertical alignment of the liquid crystal bulk layer, wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

Fig 5 and 6 schematically illustrate the difference between the devices shown in Fig 1 and Fig 4, respectively, with regard to elastic deformation.

Fig 7 schematically shows an embodiment of an out-of-plane switching liquid crystal device according to the invention exhibiting an initial planar alignment of the liquid crystal bulk layer, wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

Fig 8 and 9 schematically illustrate the difference between the devices shown in Fig 2 and Fig 7, respectively, with regard to elastic deformation.

Fig 10 schematically shows an embodiment of an in-plane switching liquid crystal device according to the invention, wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

Fig 11 schematically shows arrays of interdigitated electrodes.

Fig 12 and 13 schematically show embodiments of out-of-plane switching liquid crystal devices according to the invention, wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of same sign.

Fig 14 and 15 schematically show embodiments of out-of-plane switching liquid crystal devices according to the invention comprising two surface-director alignment layers exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

Fig 16 and 17 schematically show embodiments of out-of-plane switching liquid crystal devices according to the invention with a surface-director alignment layer having structural parts exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs.

Figs 18-20 show the rise and decay times measured for the devices according to Examples 1-3, respectively, all devices exhibiting an initial vertical alignment of the liquid crystal bulk layer.

Fig 21 shows the rise and decay times measured for the device according to Example 5 exhibiting an initial planar alignment of the liquid crystal bulk layer.

It shall be noted that the drawings are not to scale.

Detailed description of the invention

The dielectric anisotropy ($\Delta\varepsilon$) of a material having an ordered molecular structure possessing a structural anisotropy, such as a crystalline or a liquid crystalline structure, is the difference between the dielectric constants measured in perpendicular and parallel direction,

respectively, to the preferred molecular orientation in this material.

When an electric field is applied across a liquid crystal material exhibiting a positive dielectric anisotropy ($\Delta\varepsilon > 0$), the molecules will align their long axis along (or substantially along) the direction of the electric field.

When an electric field is applied across a liquid crystal material exhibiting a negative dielectric anisotropy ($\Delta\varepsilon < 0$), the molecules will align their long axis perpendicular (or substantially perpendicular) to the direction of the electric field.

The liquid crystal device according to the invention includes a liquid crystal bulk layer presenting a surface-director at a bulk surface thereof, and a surface-director alignment layer comprising side-chains arranged to interact with the bulk layer at said bulk surface for facilitating the obtaining of a preferred orientation of the surface-director of the bulk layer, wherein the orientation of the molecules of the liquid crystal bulk layer and the orientation of said side-chains of the surface-director alignment layer each is directly controllable by an electric field via dielectric coupling.

The liquid crystal device preferably includes at least one confining substrate, such as two confining substrates, at said bulk surfaces.

The surface-director alignment layer(s) is (are) preferably applied on the inner surface(s) of said substrate(s) confining the liquid crystal bulk layer.

The liquid crystal bulk layer comprises a liquid crystal material exhibiting a (non-zero) dielectric anisotropy, wherein the molecular orientation of the molecules of the liquid crystal material thus being directly controllable by an applied electric field via dielectric coupling.

The surface-director alignment layer comprises a material exhibiting a (non-zero) dielectric anisotropy and

comprising side-chains arranged to interact with said bulk layer, wherein the molecular orientation of said side-chains thus being directly controllable by an applied electric field via dielectric coupling.

As used herein, the application of an electric field over a material being "directly controllable by an applied electric field" means that the initial orientation of the molecules in the material will be affected, such as enhanced or changed (switched), as a direct consequence of the applied field.

The liquid crystal bulk layer of the device according to the invention is preferably a nematic liquid crystal.

The liquid crystal bulk layer may comprise a nematic liquid crystal material having a uniform or deformed configuration. The uniform configuration could, for instance, be planar, homeotropic or tilted. The deformed configuration could, for instance, be twisted (i.e. twisted nematic or cholesteric) or with splay and/or bent elastic deformation.

The nematic liquid crystal molecules of the bulk layer may be achiral or chiral.

Examples of suitable liquid crystal bulk layer materials having positive and negative dielectric anisotropies, respectively, are given in relation to the preferred embodiments described below.

The material of the surface-director alignment layer may either present liquid crystal properties or it may not present liquid crystal properties.

Preferably, the material of the surface-director alignment layer is a liquid crystal material, such as a nematic or smectic liquid crystal material, or liquid crystal properties are induced in an inter-phase between the surface-director alignment layer and the bulk layer when the material of the surface-director alignment layer is brought into contact with the liquid crystal bulk layer.

Preferably, the surface-director alignment layer (per se or induced in contact with the bulk layer) has a higher scalar order parameter (S), and thus a higher elastic constant (K), than the liquid crystal bulk layer. A higher scalar order parameter results in a faster switching/relaxation, and thus a shorter response time. The scalar order parameter of nematic liquid crystals is generally around 0.5 and the scalar order parameter of smectic liquid crystals is generally around 0.8-1.0. Thus, if a nematic bulk layer is used, the surface-director alignment layer should preferably provide a smectic order in contact with the bulk layer.

The material of the surface-director alignment layer may, for instance, be a polymeric material, such as a chemically modified polyvinylalcohol, polyvinyl acetal, polyimide, polysiloxane, polyacrylate, polymethacrylate, polyamide, polyester, polyurethane, etc.

The surface-director alignment layer may be produced by first applying a coating of a polymer having reactive groups on a substrate surface, and thereafter chemically attaching desired side-chains to said polymer coating by reaction with the reactive groups of the polymer, thus providing a desired surface-director alignment layer.

The surface-director alignment layer may also be produced by applying a coating of an already modified polymer on a substrate surface.

Alternatively, the surface-director alignment layer may comprise a chemically modified non-polymeric solid material, such as gold surface, a silicon dioxide surface or a glass surface (comprising silanol groups) having chemically attached side-chains.

Examples of suitable surface-director alignment layer materials having positive and negative dielectric anisotropies, respectively, are given in relation to the preferred embodiments described below. In the examples, one or more side-chains is/are attached to a polymeric backbone (Z).

The following abbreviations are used in the formulas of this application:

R1 and R2 are each independently an aliphatic hydrocarbon chain, such as an alkyl, preferably comprising 1 to 20 carbon atoms, such as 2 to 12 carbon atoms,

R3 (represents spacing atoms) is a an aliphatic hydrocarbon, such as an alkyl, a siloxane, an ethylene glycol chain, or any combination thereof, comprising at least 2, preferably 2 to 20, such as 4 to 20, more preferably 5 to 20, carbon atoms or heteroatoms (it shall be noted that the number of carbon atoms or heteroatoms may be randomly varied along the polymer main chain),

R4 is an aliphatic hydrocarbon chain, such as an alkyl, preferably comprising 1 to 20 carbon atoms, such as 1 to 5 carbon atoms,

R5 and R6 are each independently an aliphatic hydrocarbon, a siloxane, an ethylene glycol chain, or any combination thereof, preferably comprising 4 to 22, such as 6 to 20, more preferably 8 to 18, such as 9 to 15, carbon atoms or heteroatoms,

X and Y are each independently H, F, Cl, CN, or CF_3,

X_1 and Y_1 are each independently F or Cl, preferably F, and

Z is part of a polymer main chain (polymeric backbone).

In this context, it shall be noted that at least some of the side-chains (S_n) of the surface-director alignment layer material should be free to move their molecular orientation as a direct consequence of their dielectric coupling to an applied electric field (i.e. directly controllable). Thus, the physical intra-molecular interaction between said side-chains and the rest of the surface-director alignment layer material should preferably be weak. A low degree of interaction may, for instance, be obtained by selecting a surface-director alignment layer material having a weak physical intramolecular interaction between said side-chains and the

rest of the material or by sterically preventing such physical intra-molecular interaction, e.g. by the use of spacers between said side-chains and the rest of the material.

The surface-director alignment layer in the device according to the invention preferably comprises a polymer as defined in the co-pending international patent application PCT/SE2004/000300. This type of polymers comprises a polymeric backbone (Z), preferably a polyvinyl acetal, and side-chains (S_n) attached thereto, wherein the polymeric backbone lacks directly coupled ring structures, and each side-chain of at least some of the side-chains comprises at least two unsubstituted and/or substituted phenyls coupled via a coupling selected from the group consisting of a carbon-carbon single bond (-), a carbon-carbon double bond containing unit (-CH=CH-), a carbon-carbon triple bond containing unit (-C≡C-), a methylene eter unit ($-CH_2O-$), an ethylene eter unit ($-CH_2CH_2O-$), an ester unit (-COO-) and an azo unit (-N=N-), exhibits a permanent and/or induced dipole moment that in ordered phase provides dielectric anisotropy, and is attached to the polymeric backbone via at least two spacing atoms, preferably at least five spacing atoms. The preparation of this type of polymers is described in PCT/SE2004/000300.

As used herein a "side-chain" means a grouping of atoms that branches off from a straight-chain molecule, such as a polymeric backbone.

As used herein "an unsubstituted phenyl" means a phenyl group, such as $-C_6H_4-$ and $-C_6H_5$.

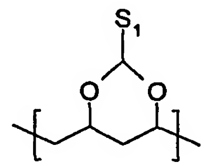
As used herein "a substituted phenyl" means a phenyl group wherein one or more hydrogen atom(s) has (have) been replaced by (a) different atom(s) or group(s).

As used herein "spacing atoms" means atoms linking a side-chain to a polymeric backbone.

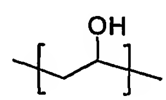
As used herein "directly coupled ring structures" means fused ring structures and ring structures coupled

with single or multiple bonds only (i.e. ring structures coupled with one or more bonds only).

Preferably, said polymeric backbone lacking directly coupled ring structures comprises a first type of randomly distributed units according to

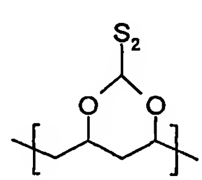


wherein S_1 represents a first side-chain comprising at least two unsubstituted and/or substituted phenyls coupled via a coupling selected from the group consisting of a carbon-carbon single bond (-), a carbon-carbon double bond containing unit (-CH=CH-), a carbon-carbon triple bond containing unit (-C≡C-), a methylene eter unit ($-CH_2O-$), an ethylene eter unit ($-CH_2CH_2O-$), an ester group unit (-COO-) and an azo unit (-N=N-) and exhibiting a permanent and/or induced dipole moment that in ordered phase provides dielectric anisotropy, and at least two spacing atoms through which the first side-chain is attached to the polymeric backbone, and a second type of randomly distributed units according to



When the polymeric backbone comprises these types of randomly distributed units, the polymer is a polyvinyl acetal.

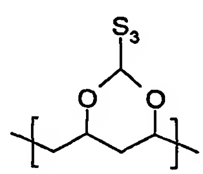
Furthermore, the polymeric backbone may preferably also comprise a third type of randomly distributed units according to



wherein S_2 represents a second side-chain, being different from S_1, exhibiting a permanent and/or induced dipole moment that in ordered phase provides dielectric anisotropy, and at least two spacing atoms through which the second side-chain is attached to the polymeric backbone. The dielectric anisotropy provided by S_2 may be different from the dielectric anisotropy provided by S_1.

Preferably, said second side-chain S_2 comprises at least two unsubstituted and/or substituted phenyls coupled via a coupling selected from the group consisting of a carbon-carbon single bond (-), a carbon-carbon double bond containing unit (-CH=CH-), a carbon-carbon triple bond containing unit (-C≡C-), a methylene eter unit ($-CH_2O-$), an ethylene eter unit ($-CH_2CH_2O-$), an ester unit (-COO-) and an azo unit (-N=N-).

The polymeric backbone may also comprise a further (third or fourth) type of randomly distributed units according to



wherein S_3 represents a side-chain, being different from S_1 and S_2, exhibiting no permanent and/or induced dipole moment and thus providing no dielectric anisotropy. This type of unit may be incorporated in the polymeric backbone to obtain a polymer exhibiting a certain desired dielectric anisotropy in ordered phase using a desired specific side-chain S_1, optionally in combination with a desired specific side-chain S_2. Thus, the dielectric anisotropy of the polymer in ordered phase may be reduced using a side-chain S_3 exhibiting no permanent and/or induced dipole moment and thus providing no dielectric anisotropy.

The device according to the invention is preferably either an out-of-plane switching or an in-plane switching liquid crystal device.

1. Opposite signs of dielectric anisotropy

In a first group of embodiments of the device according to the invention, the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of opposite signs. Said device is preferably an out-of-plane switching liquid crystal device.

a) Out-of-plane switching liquid crystal devices

In an out-of-plane switching device, according to this first group of embodiments of the invention, having an initial planar alignment, an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on the confining substrates, termed projected surface-director, presents said preferred orientation in a geometrical plane in parallel with said substrates, termed preferred field-off planar orientation, and the orientation of the molecules of said bulk layer is directly controllable by an applied electric field to perform an out-of-plane switching of said preferred planar orientation of the projected surface-director to a field-induced vertical orientation.

In an out-of-plane switching device, according to this first group of embodiments, having an initial vertical alignment, an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on a geometrical plane perpendicular to said substrates, termed projected surface-director, presents said preferred orientation, termed preferred field-off vertical orientation, and the orientation of the molecules of said bulk layer is directly controllable by an applied electric field to perform an out-of-plane switching of said preferred vertical orientation of the projected surface-director to a field-induced planar orientation.

In an out-of-plane switching device according to the invention, the electric field is applied normally to the confining substrates (i.e. normally to the liquid crystal bulk layer).

Fig 4 shows part of an embodiment of an out-of-plane switching liquid crystal device 5 according to the invention, wherein surface-director alignment layers 6 are applied on the inner surfaces of substrates 7 confining a liquid crystal bulk layer 8. The liquid crystal bulk 8 exhibits a negative dielectric anisotropy ($\Delta\varepsilon < 0$) and the surface-director alignment layers 6 exhibit a positive dielectric anisotropy ($\Delta\varepsilon > 0$).

The molecules (i.e. the side-chains) of the surface-director alignment layers 6 have in this embodiment an initial vertical orientation in relation to the confining substrate surfaces 7, thus resulting in vertically or substantially vertically aligned liquid crystal bulk molecules 8 in the field-off state ($E = 0$). The surface-director alignment layers 6 are also preferably unidirectionally rubbed to obtain a preferred orientation of a field-induced planar alignment of the liquid crystal bulk molecules 8.

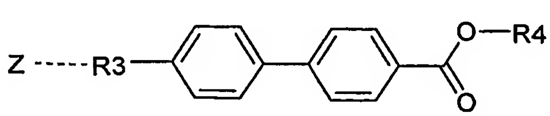
It shall be noted that even though the device 5 shown in Fig 4 comprises two surface-director alignment layers 6 (two-sided embodiment), the device according to the invention may alternatively comprise, for instance, only one surface-director alignment layer (one-sided embodiment).

When an external electric field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 8 between electrodes 9 on the confining substrates 7, the liquid crystal bulk molecules 8 aligned vertically or substantially vertically will, due to their negative dielectric anisotropy, switch out-of-plane to a field-induced planar orientation. The molecules (i.e. the side-chains) of the surface-director alignment layers 6 will, however, keep their initial vertical orientation which will be enhanced

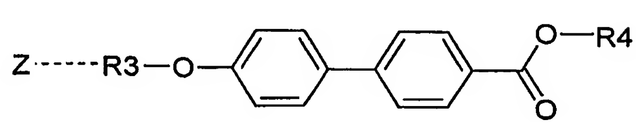
and stabilized by the applied field due to their positive dielectric anisotropy. In other words, the molecules (i.e. the side-chains) of the surface-director alignment layers 6 will not switch when an electric field is applied across the layers 6, thus causing a strong elastic deformation D3 of the liquid crystal layer 8 near the substrate surface 7. When the external field is removed (E = 0), the vertically oriented molecules (i.e. the side-chains) of the surface-director alignment layers 6 will promote a fast relaxation from the field-induced planar orientation of the liquid crystal bulk molecules 8 back to their field-off vertical orientation. Thus, the elastic deformation D3 shown in Fig 4 is stronger than the elastic deformation D1 shown in Fig 1, and therefore the relaxation to the field-off orientation will in this case be faster than in the case shown in Fig 1. The comparison of D1 and D3, respectively, is also schematically shown in Fig 5 and Fig 6, respectively.

The liquid crystal bulk layer 8 may have a negative dielectric anisotropy within the range of from -6 to -1, and the surface-director alignment layers 6 may have a positive dielectric anisotropy within the range of from 1 to 30.

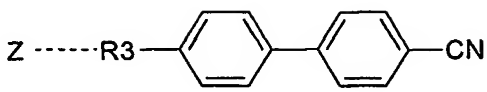
Formulas I-X are examples of surface-director alignment layer materials suitable for providing an initial field-off vertical alignment in the above described embodiment (an out-of-plane switching liquid crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide positive dielectric anisotropy.



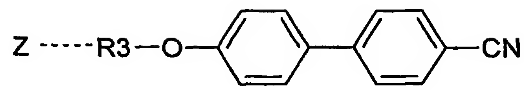
Formula I



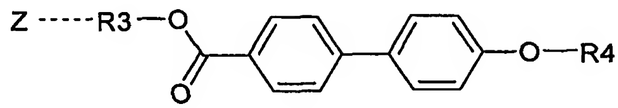
Formula II



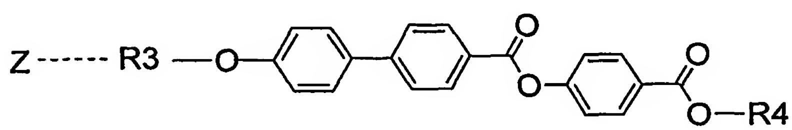
Formula III



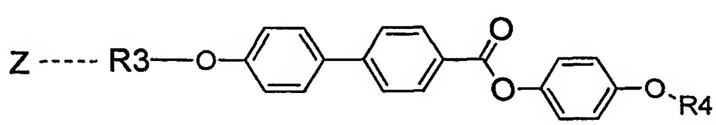
Formula IV



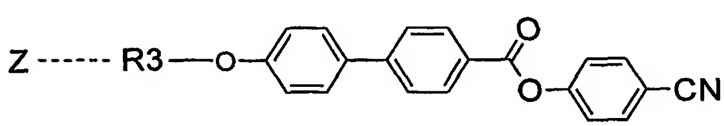
Formula V



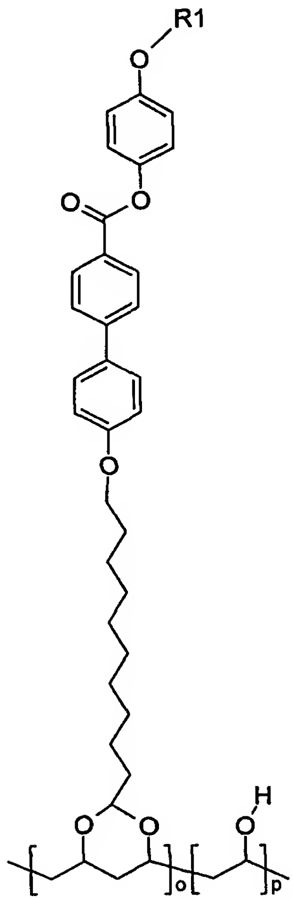
Formula VI



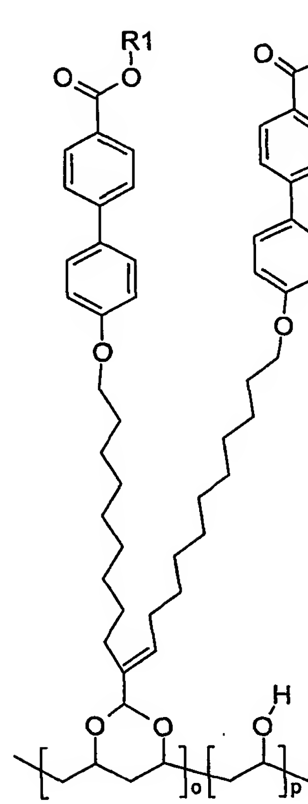
Formula VII



Formula VIII

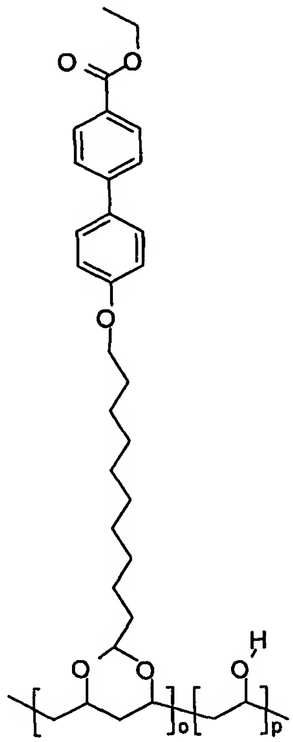


Formula IX

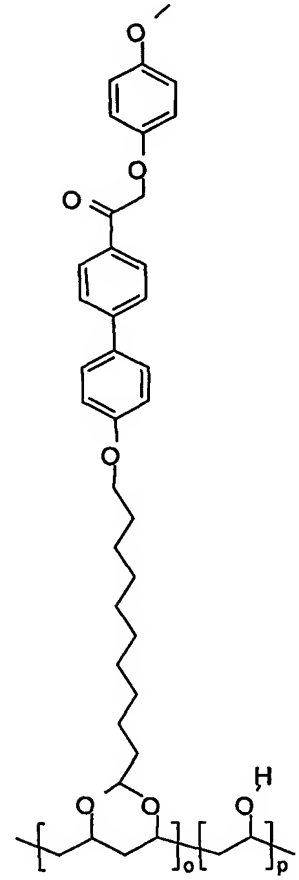


Formula X

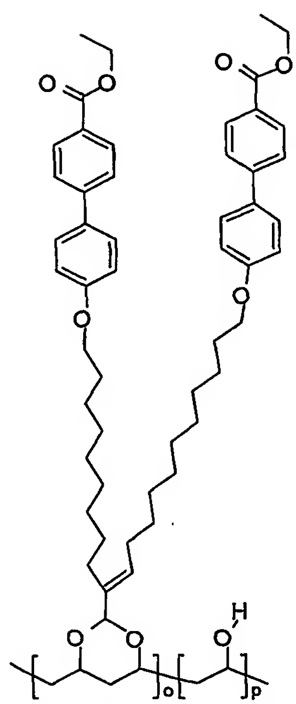
Specific examples of this type of polymers suitable as surface-director alignment layer materials in the above described embodiment are represented by Formulas XI-XIII.



Formula XI

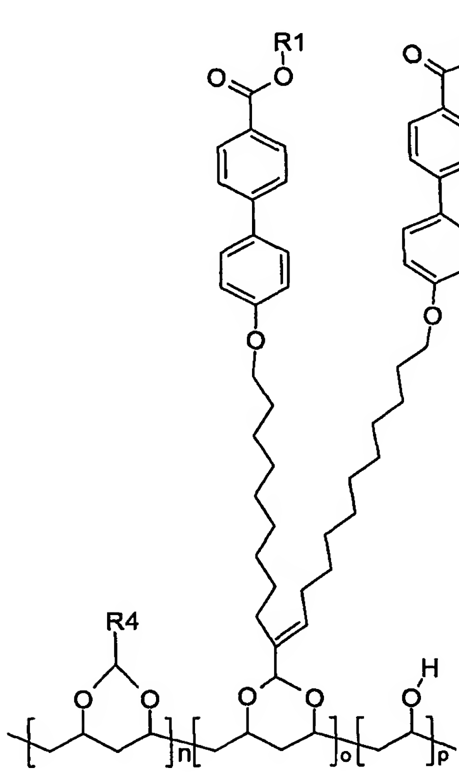


Formula XII

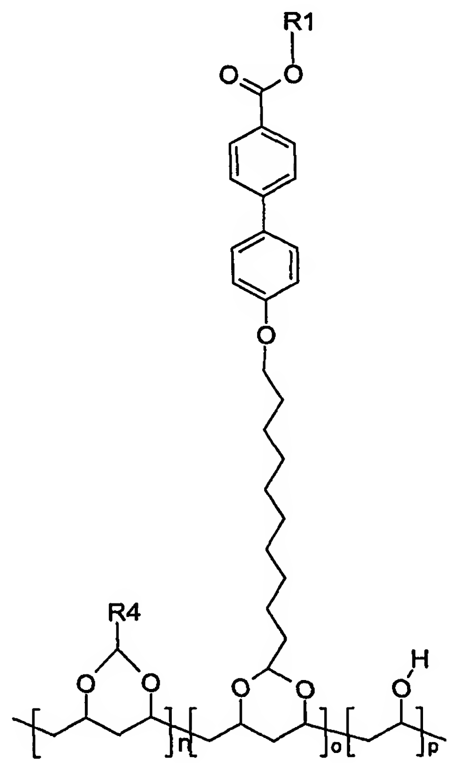


Formula XIII

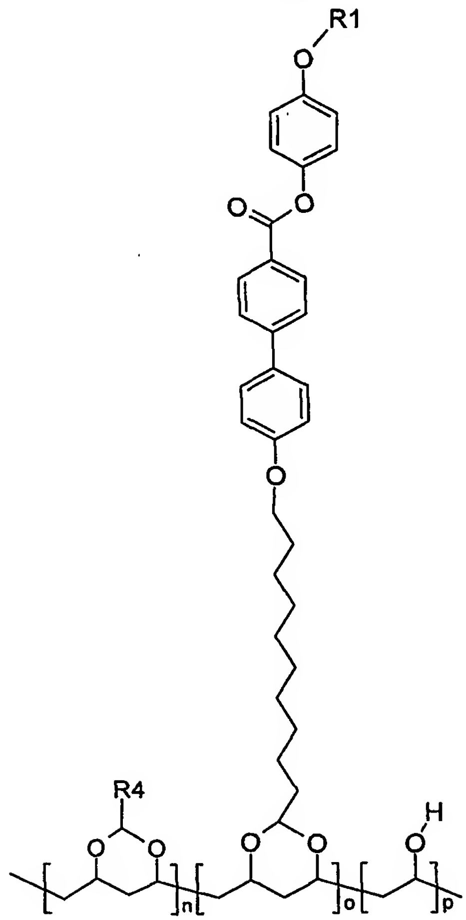
Formulas XIV-XVI are further examples of surface-director alignment layer materials suitable for providing an initial field-off vertical alignment in the above described embodiment (an out-of-plane switching liquid crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide positive dielectric anisotropy and chemically bound side-chains (S_3) exhibiting no permanent and/or induced dipole moments and thus providing no dielectric anisotropy.



Formula XIV

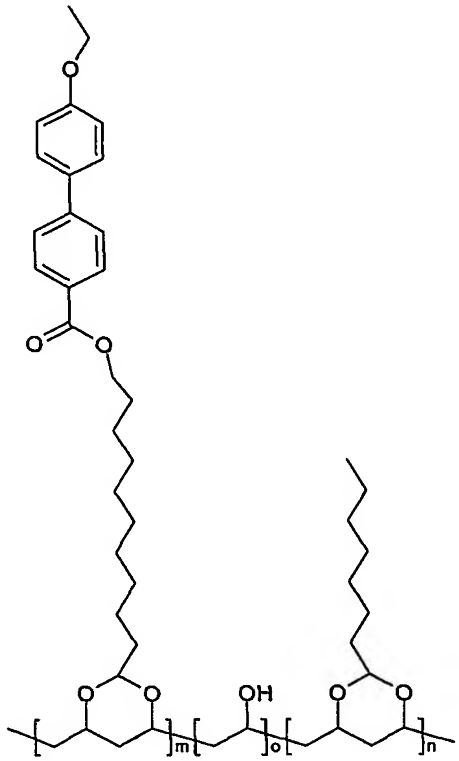


Formula XV

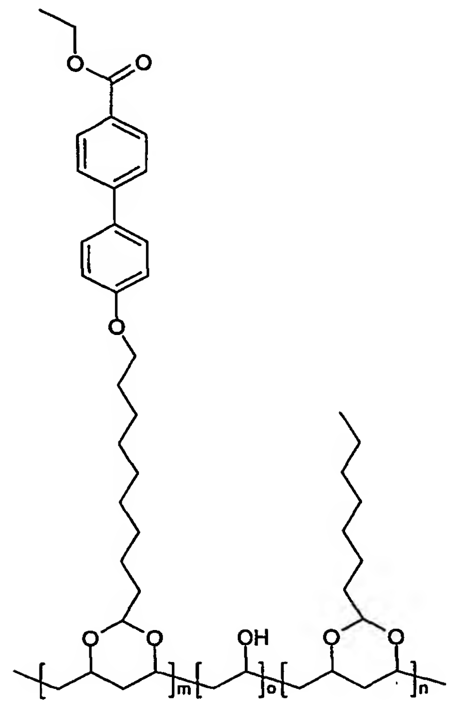


Formula XVI

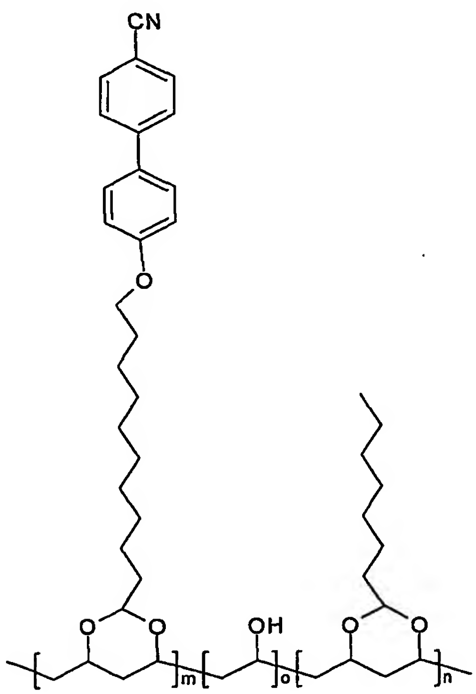
Specific examples of this type of polymers suitable as surface-director alignment layer materials in the above described embodiment are represented by Formulas XVII to XXVIII:



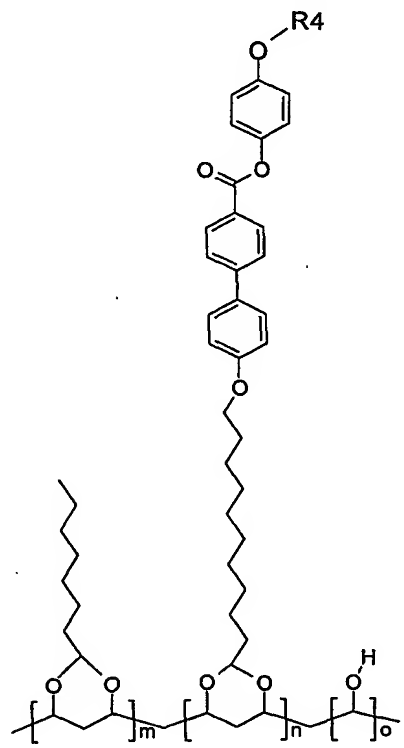
Formula XVII



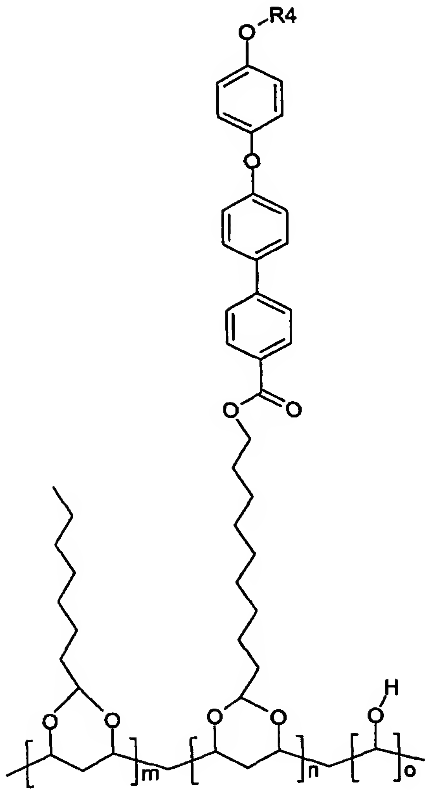
Formula XVIII



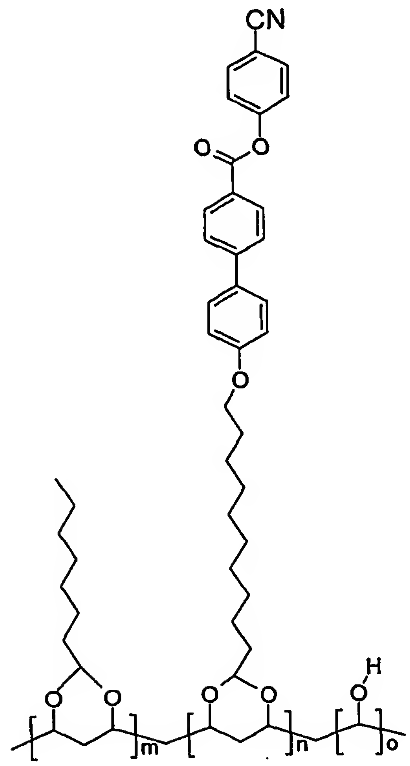
Formula XIX



Formula XX

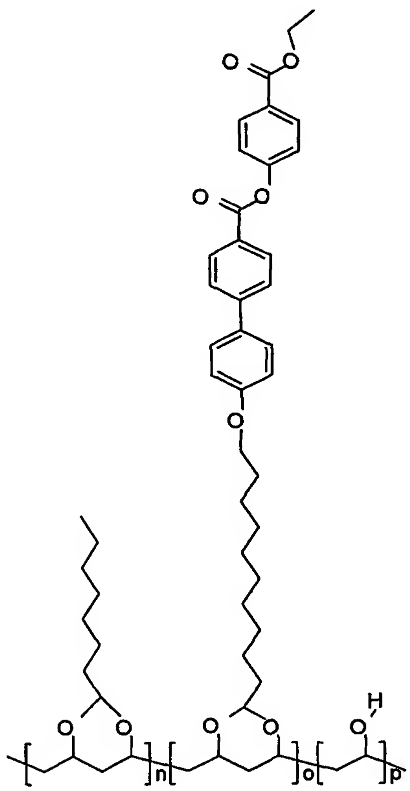


Formula XXI

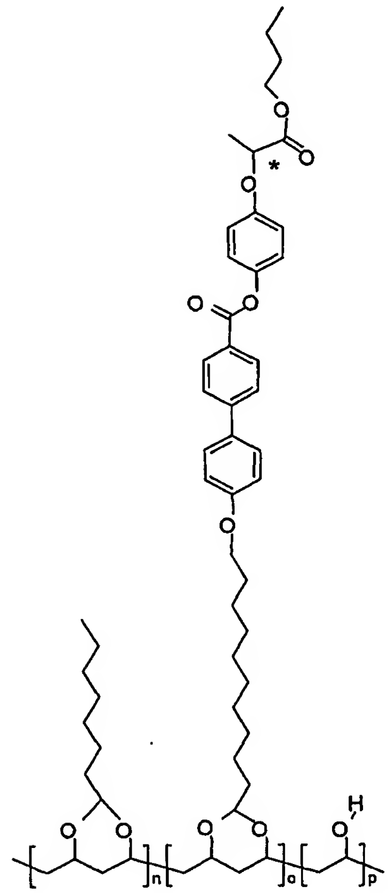


Formula XXII

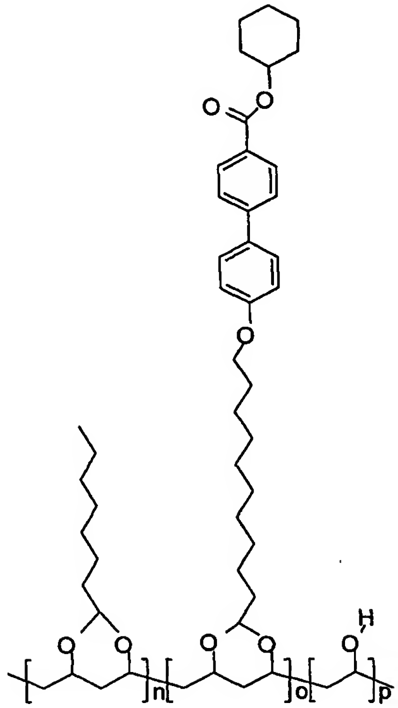
wherein R4 is CH_3 and (m+n)/o is within the range of from 25/50 to 43/14, preferably above 40/20, such as 42/16, and m/n is within the range of from 9/1 to 1/9, preferably 3/1 to 1/3, such as 2/1, and



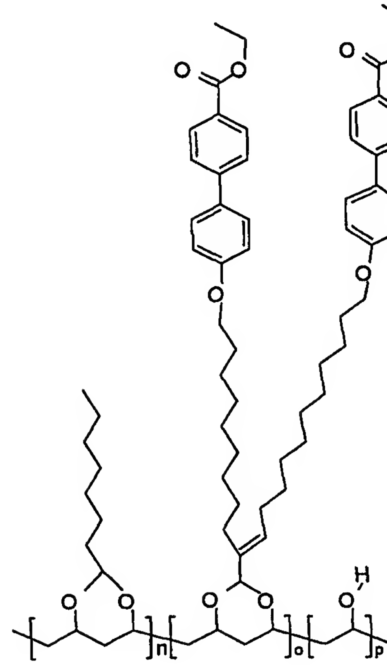
Formula XXIII



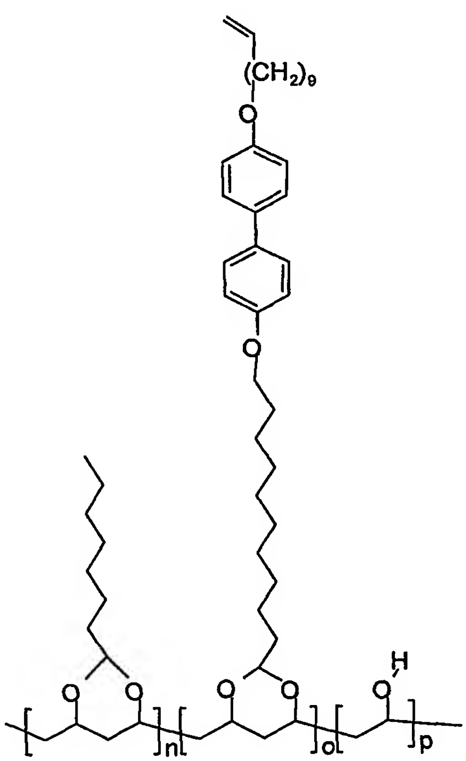
Formula XXIV



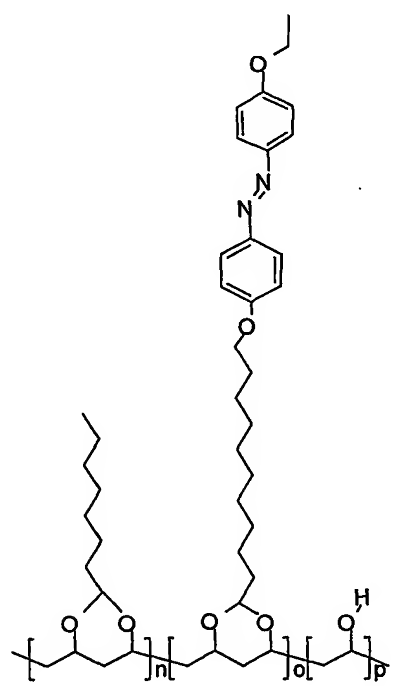
Formula XXV



Formula XXVI

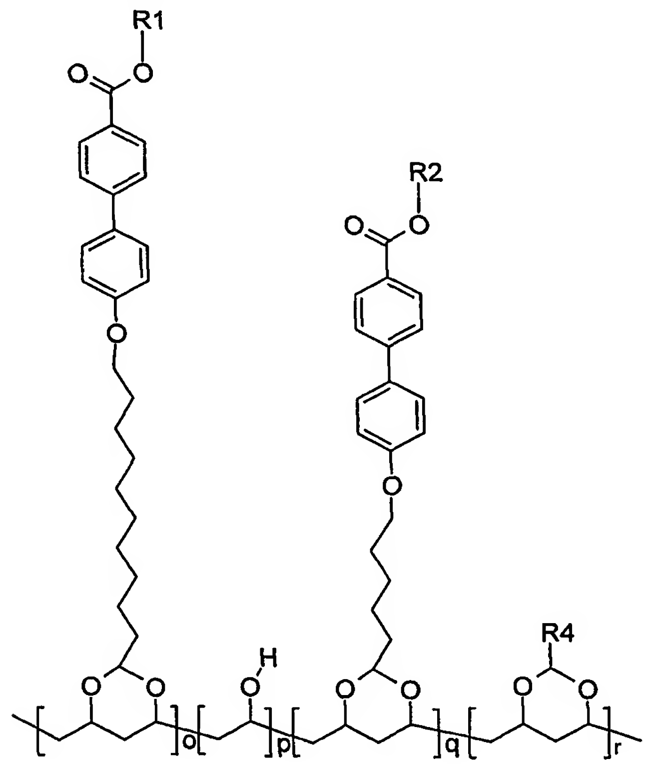


Formula XXVII



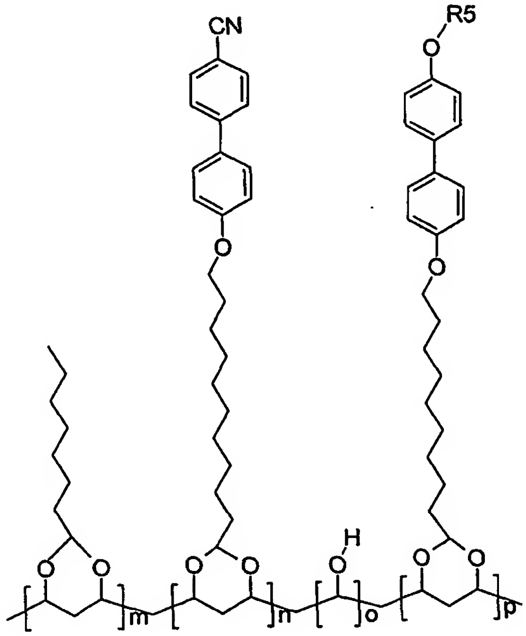
Formula XXVIII

Formula XXIX represents further examples of surface-director alignment layer materials suitable for providing an initial field-off vertical alignment in the above described embodiment (an out-of-plane switching liquid crystal device). These polymers comprise two different types of side-chains (S_1 and S_2) exhibiting permanent and/or induced dipole moments that in ordered phase provide positive dielectric anisotropy and side-chains (S_3) exhibiting no permanent and/or induced dipole moments and thus providing no dielectric anisotropy.

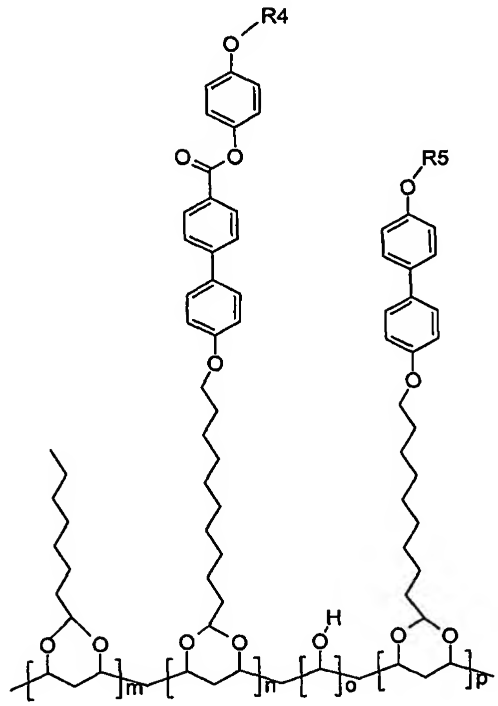


Formula XXIX

Specific examples of this type of polymers suitable as surface-director alignment layer materials in the above described embodiment are represented by Formulas XXX to XXXII:

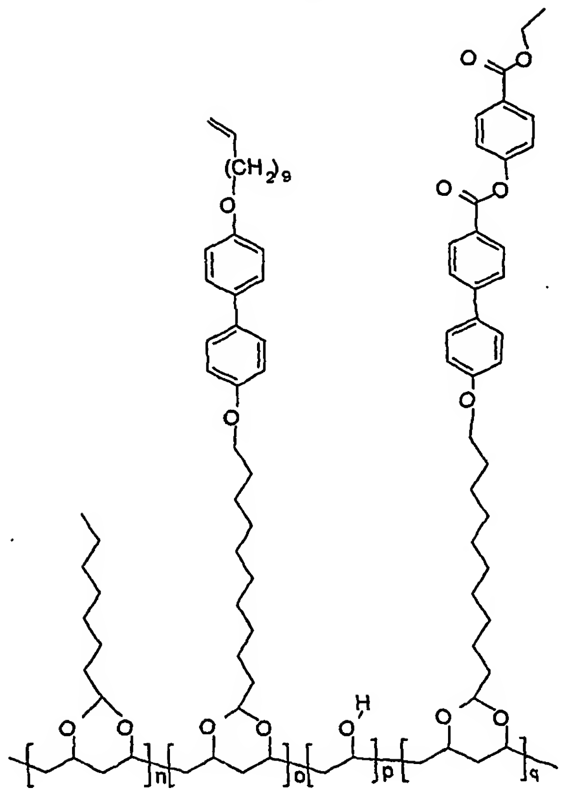


Formula XXX



Formula XXXI

wherein R4 is CH_3, R5 is CH_3, and (m+n)/o is within the range of from 25/50 to 43/14, preferably above 40/20, such as 42/16, and m/n is within the range of from 9/1 to 1/9, preferably 3/1 to 1/3, such as 2/1, and



Formula XXXII

Instead of using a polymer, the side-chains of Formulas I to XXXII can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

It shall be noted that in an embodiment of an out-of-plane switching device according to the invention comprising two surface-director alignment layers applied on substrate surfaces confining the liquid crystal bulk layer, and wherein the surface-director alignment layer exhibit a positive dielectric anisotropy and the liquid crystal bulk layer exhibit a negative dielectric anisotropy, the dipole moments of the side-chains of each sur-

face-director alignment layer may either have the same direction or opposite directions.

Such a device having two separate alignment layers exhibiting the same directions of dipole moments is exemplified by a device having two separate alignment layers of the material according to Formula XIX (or Formula XVIII).

Such a device having two separate alignment layers exhibiting the opposite directions of dipole moments is exemplified by a device having one alignment layer of the material according to Formula XIX (or Formula XVIII) and one alignment layer of the material according to Formula XVII.

Examples of liquid crystal bulk layer materials having a negative dielectric anisotropy, and being suitable in the above described embodiment, are a mixture of MLC 6608 ($\Delta\varepsilon = -4.2$) and MBBA ($\Delta\varepsilon = -0.8$), a mixture of MLC 6884 ($\Delta\varepsilon = -5.0$) and MBBA ($\Delta\varepsilon = -0.8$), and a mixture of MDA 98-3099 ($\Delta\varepsilon = -6$) and MBBA ($\Delta\varepsilon = -0.8$), all of which are nematic liquid crystal materials supplied by Merck.

Fig 7 shows part of another embodiment of an out-of-plane switching liquid crystal device 10 according to the invention, wherein surface-director alignment layers 11 are applied on the inner surfaces of substrates 12 confining a liquid crystal bulk layer 13. The liquid crystal bulk 13 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$) and the surface-director alignment layers 11 exhibit a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

The molecules (i.e. the side-chains) of the surface-director alignment layers 11 have in this embodiment an initial planar orientation in relation to the confining substrate surfaces 12, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules 13 in the field-off state ($E = 0$). The surface-director alignment layers 11 is also preferably unidirectionally rubbed to obtain a preferred orientation of planar align-

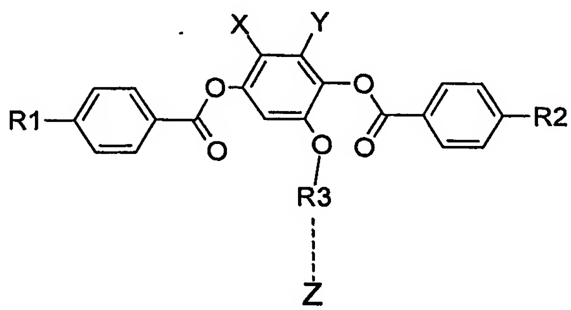
ment of the liquid crystal bulk molecules (in field-off state).

It shall be noted that even though the device 10 shown in Fig 7 comprises two surface-director alignment layers 11 (two-sided embodiment), the device according to the invention may alternatively comprise, for instance, only one surface-director alignment layer (one-sided embodiment).

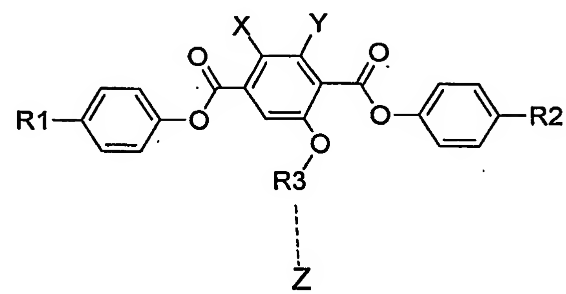
When an external electric field ($E \neq 0$) is applied normally to the liquid crystal bulk layer 13 between electrodes 14 on the confining substrates 12, the liquid crystal bulk molecules 13 aligned planar or substantially planar will, due to their positive dielectric anisotropy, switch out-of-plane to a field-induced vertical orientation. The molecules (i.e. the side-chains) of the surface-director alignment layers 11 will, however, keep their initial uniform planar orientation which will be enhanced and stabilized by the applied electric field due to their negative dielectric anisotropy. In other words, the molecules (i.e. the side-chains) of the surface-director alignment layers 11 will not switch when an electric field is applied across the layers 11. When the external field is removed ($E = 0$), the planar oriented molecules (i.e. the side-chains) of the surface-director alignment layers 11 will promote a fast relaxation from the field-induced vertical orientation of the liquid crystal bulk molecules 13 back to their initial field-off planar orientation. Thus, the elastic deformation D4 shown in Fig 7 is stronger than the elastic deformation D2 shown in Fig 2. The comparison of D2 and D4 respectively, is also schematically shown in Fig 8 and Fig 9, respectively.

The liquid crystal bulk layer 13 may have a positive dielectric anisotropy within the range of from 1 to 30, and the surface alignment layers 11 may have a negative dielectric anisotropy within the range of from -6 to -1.

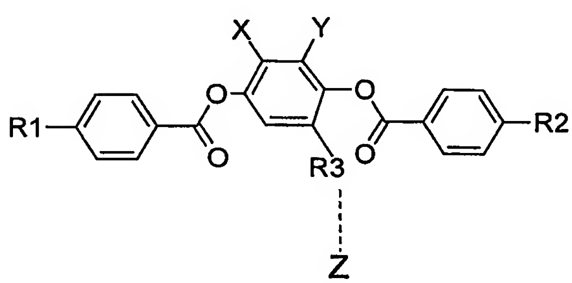
Formulas XXXIII to XLIII are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described embodiment (an out-of-plane liquid crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide negative dielectric anisotropy.



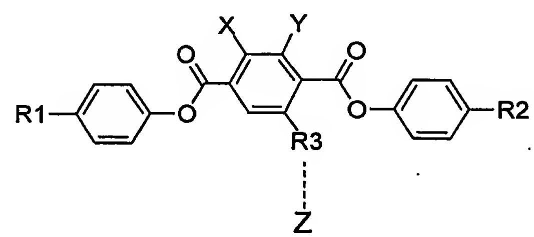
Formula XXXIII



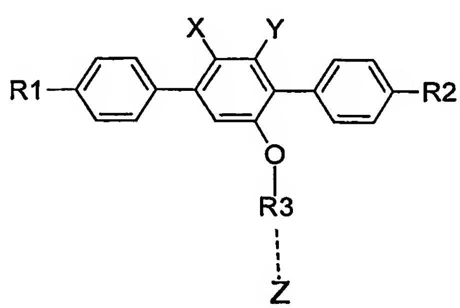
Formula XXXIV



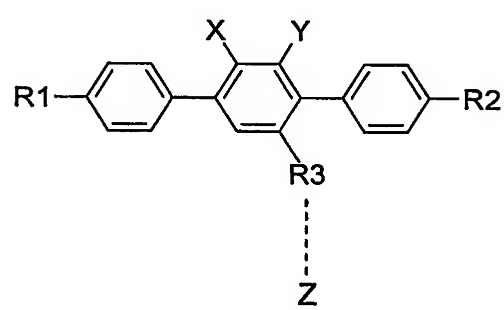
Formula XXXV



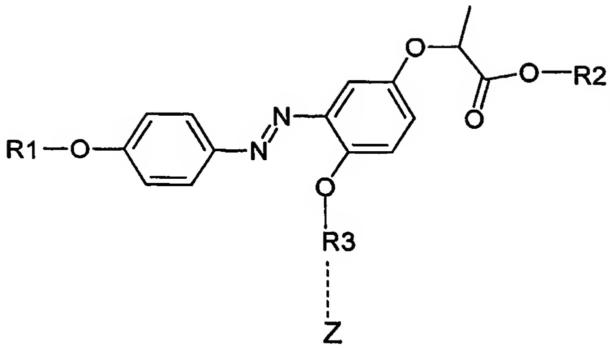
Formula XXXVI



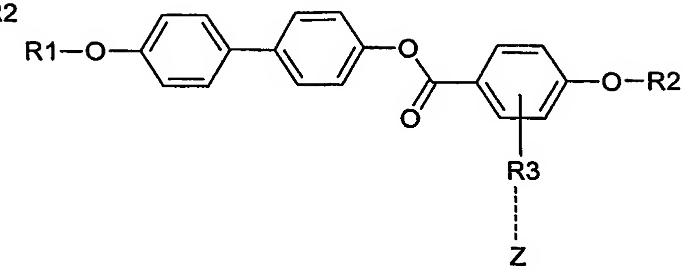
Formula XXXVII



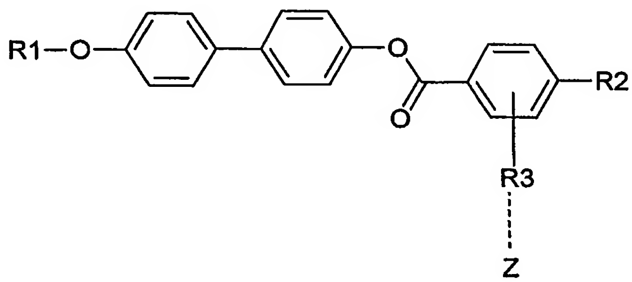
Formula XXXVIII



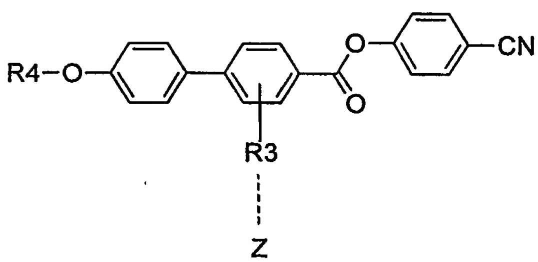
Formula IXL



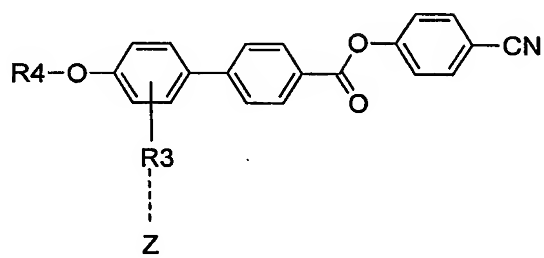
Formula XL



Formula XLI



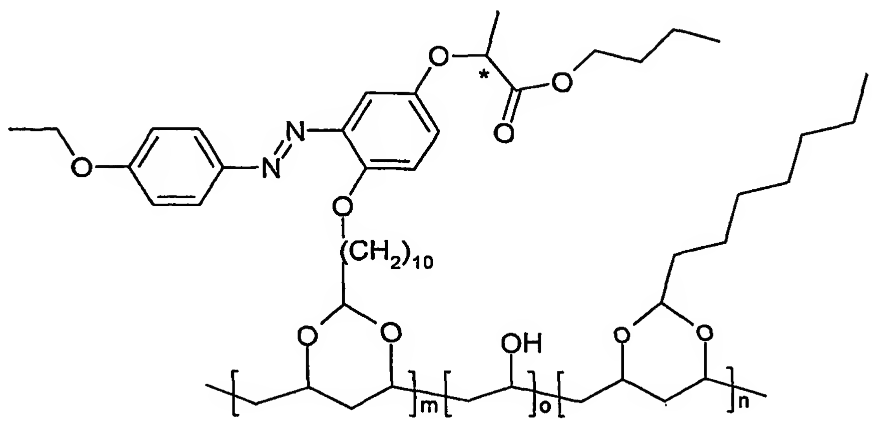
Formula XLII



Formula XLIII

A specific example of a surface-director alignment material suitable for providing an initial field-off planar alignment in the above described embodiment (an out-of-plane switching liquid crystal device) is the polymer according to Formula XLIV. This polymer comprises side-chains (S_1) exhibiting permanent and/or induced dipole moments that in ordered phase provides negative dielectric anisotropy and side-chains (S_3) exhibiting no perma-

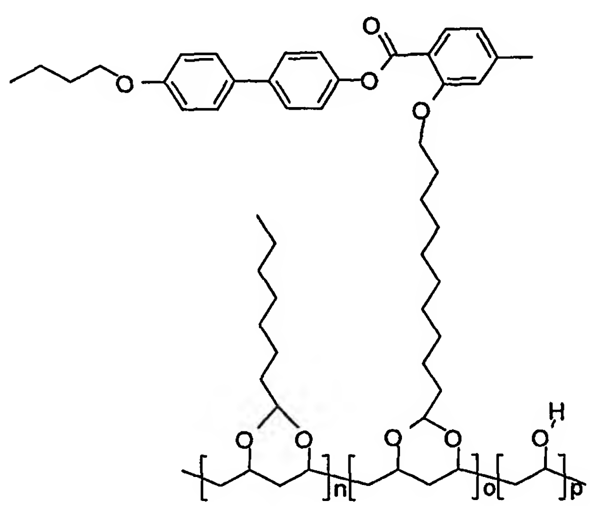
nent and/or induced dipole moments and thus providing no dielectric anisotropy.



Formula XLIV

wherein (m+n)/o is within the range of from 25/50 to 43/14, preferably above 40/20, such as 43/18, and m/n is within the range of from 9/1 to 1/9, preferably 3/1 to 1/3, such as 1/1.

Another specific example of this type of polymers suitable as surface-director alignment layer material in the above described embodiment is represented by Formula XLV.



Formula XLV

Instead of using a polymer, the side-chains of Formulas XXXIII to XLV can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

Examples of liquid crystal bulk layer materials having a positive dielectric anisotropy, and being suitable in the above described embodiment, are E44 ($\Delta\varepsilon = +16.8$), E9 ($\Delta\varepsilon = +16.5$), and E70 A ($\Delta\varepsilon = +10.8$), all of which are nematic liquid crystal materials supplied by BDH/Merck.

The embodiments shown in Fig 4 and 7 include out-of-plane switching liquid crystal devices, each device comprising a liquid crystal bulk layer and a surface-director alignment layer exhibiting dielectric anisotropies of opposite signs. It shall be noted that the combination of a surface-director alignment layer and a liquid crystal bulk layer exhibiting dielectric anisotropies of opposite signs is also applicable and advantageous for in-plane switching liquid crystal devices (described below), even though the effect of a decreased decay time is more pronounced for out-of-plane switching liquid crystal devices. Thus, the device according to the invention wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies of opposite signs is preferably an out-of-plane switching liquid crystal device.

b) In-plane switching liquid crystal devices

In an in-plane switching device, according to said first group of embodiments of the invention, having an initial first planar alignment, an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on said substrates, termed projected surface-director, presents said preferred orientation in a geometrical plane in parallel with said substrate, termed preferred field-off planar orientation, and the orienta-

tion of the molecules of said bulk layer is directly controllable by an applied electric field to perform an in-plane switching of said preferred planar orientation of the projected surface-director to a field-induced second planar orientation.

In in-plane switching devices according to the invention, the electric field is applied in parallel with the confining substrates (i.e. along the liquid crystal bulk layer).

Fig 10 shows part of an embodiment of an in-plane switching liquid crystal device 15 according to the invention, wherein surface-director alignment layers 16 are applied on the inner surfaces of substrates 17 (only one substrate is shown) confining a liquid crystal bulk layer 18. The liquid crystal bulk 18 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$) and the surface-director alignment layers 16 exhibit a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

The molecules (i.e. the side-chains) of the surface-director alignment layers 16 have in this embodiment an initial planar orientation, in a first direction, in relation to the confining substrate surfaces 17, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules 18 in the field-off state ($E = 0$), Fig 10a. The surface-director alignment layers 16 is preferably unidirectionally rubbed to obtain the preferred field-off first planar orientation direction.

It shall be noted that the device 15 shown in Fig 10 may either comprise two surface-director alignment layers 16 (two-sided embodiment) or alternatively only one surface-director alignment layer 16 (one-sided embodiment).

When an external electric field is applied ($E \neq 0$), Fig 10b, along the liquid crystal bulk layer 18 (in parallel with the confining substrates) between electrodes 19 placed as shown in Fig 4, the liquid crystal bulk molecules 18 will, due to their positive dielectric anisotropy, switch in-plane to a field-induced second planar

orientation direction along the direction of the applied field. The molecules (i.e. the side-chains) of the surface-director alignment layers 16 will, however, keep their initial first planar orientation direction which will be enhanced and stabilized by the applied field due to their negative dielectric anisotropy. In other words, the molecules (i.e. the side-chains) of the surface-director alignment layers 16 will not switch when an electric field is applied along the layers 16. When the external field is removed (E = 0), the molecules (i.e. the side-chains) of the surface-director alignment layers 16 having the first planar orientation direction will promote a fast relaxation from the field-induced second planar orientation direction of the liquid crystal bulk molecules 18 back to their initial field-off planar first orientation direction.

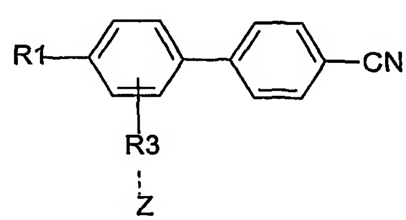
Formulas XXXIII to XLV are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described embodiment (an in-plane switching liquid crystal device). As previously described, these polymers comprise side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide negative dielectric anisotropy.

Instead of using a polymer, the side-chains of Formulas XXXIII to XLV can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

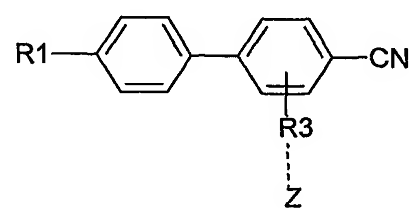
Examples of suitable liquid crystal bulk layer materials having a positive dielectric anisotropy, and being suitable in the above described embodiment, are E44 ($\Delta\varepsilon$ = +16.8), E9 ($\Delta\varepsilon$ = +16.5), and E70 A ($\Delta\varepsilon$ = +10.8), all of which are nematic liquid crystal materials supplied by BDH/Merck.

Another similar embodiment of an in-plane switching liquid crystal device according to the invention is a device comprising a liquid crystal bulk exhibiting a negative dielectric anisotropy ($\Delta\varepsilon < 0$) and at least one, preferably two, surface-director alignment layer(s) exhibiting a positive dielectric anisotropy ($\Delta\varepsilon > 0$).

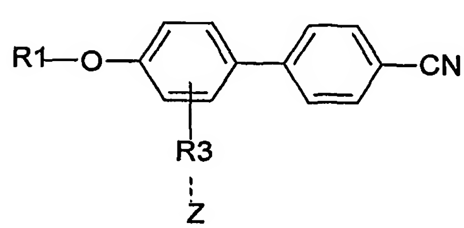
Formulas XLVI to LXII are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described embodiment (an in-plane switching liquid crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provides positive dielectric anisotropy.



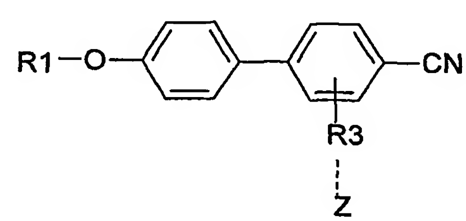
Formula XLVI



Formula XLVII



Formula XLVIII



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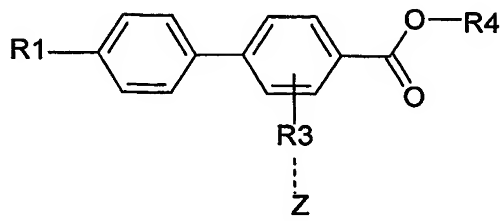
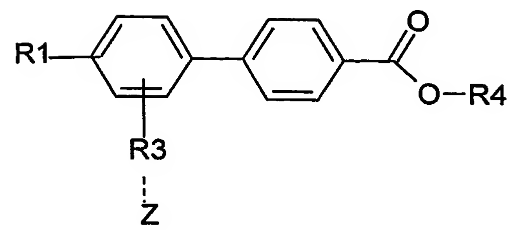
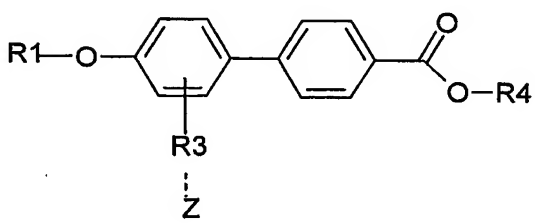


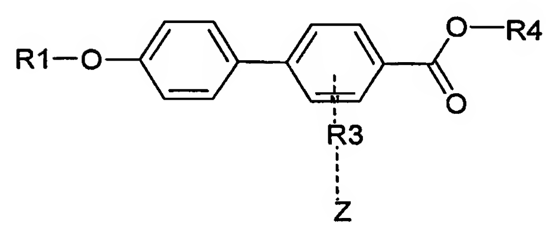
Formula L



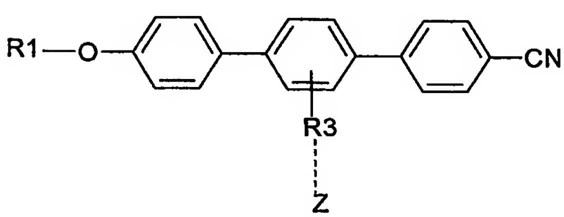
Formula LI



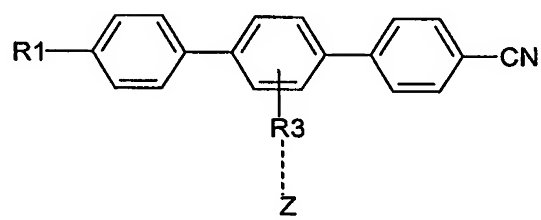
Formula LII



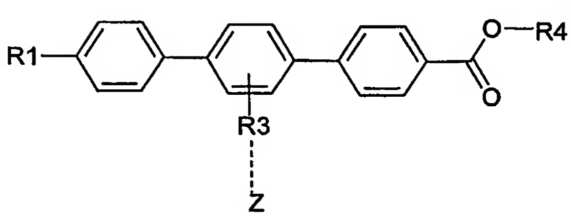
Formula LIII



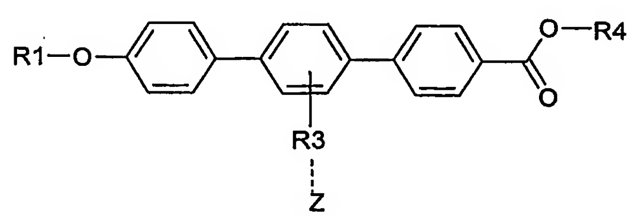
Formula LIV



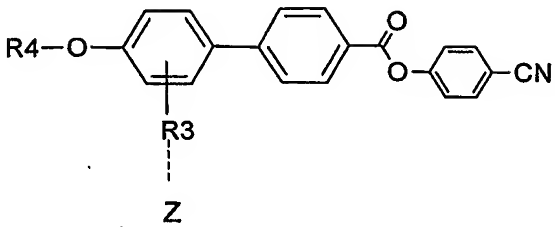
Formula LV



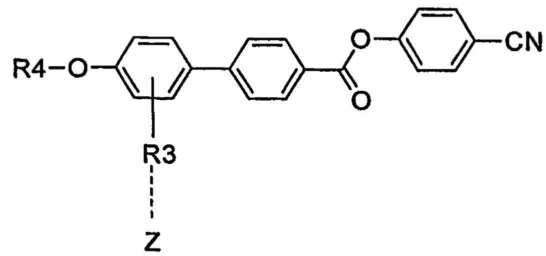
Formula LVI



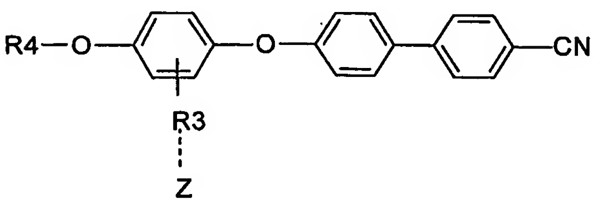
Formula LVII



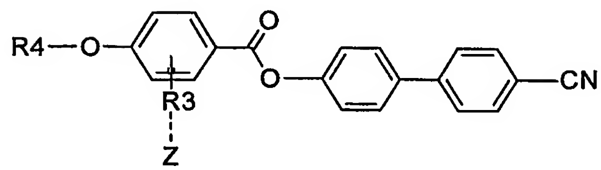
Formula LVIII



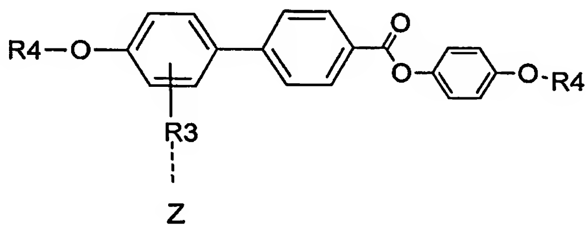
Formula LIX



Formula LX

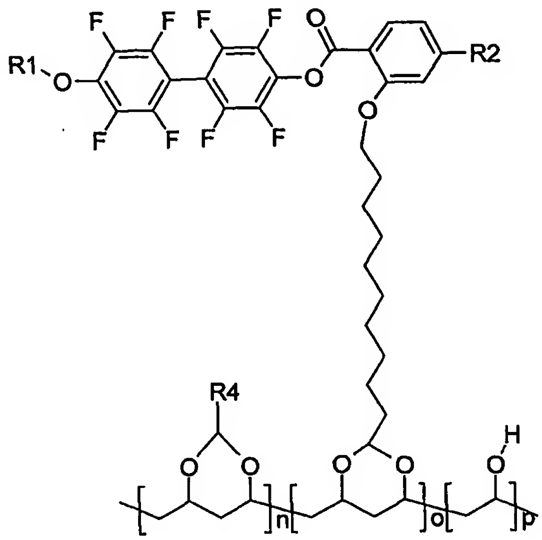


Formula LXI

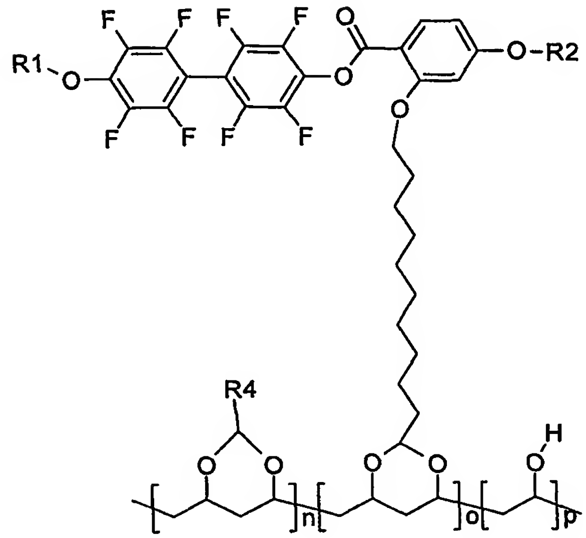


Formula LXII

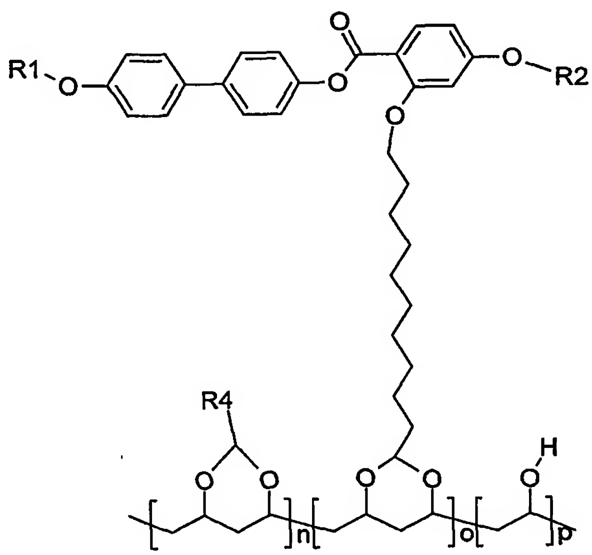
Formulas LXIII to LXVII are further examples of surface-director alignment layer materials suitable for providing an initial field-off planar alignment in the above described embodiment (an in-plane switching liquid crystal device). These polymers comprise side-chains (S_1) exhibiting permanent and/or induced dipole moments that in ordered phase provides positive dielectric anisotropy and side-chains (S_3) exhibiting no permanent and/or induced dipole moments and thus providing no dielectric anisotropy.



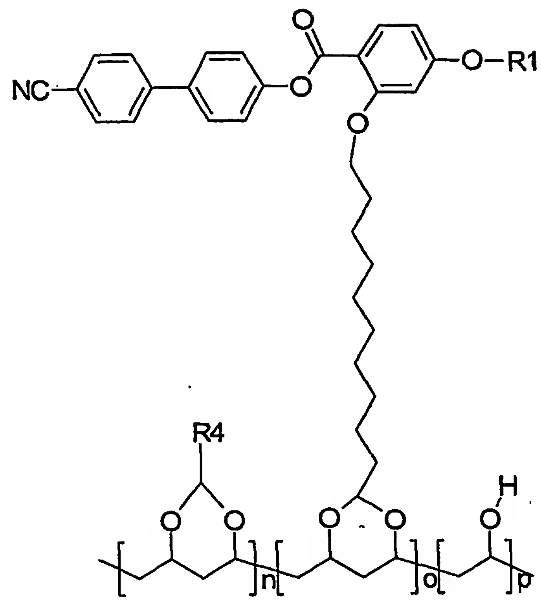
Formula LXIII



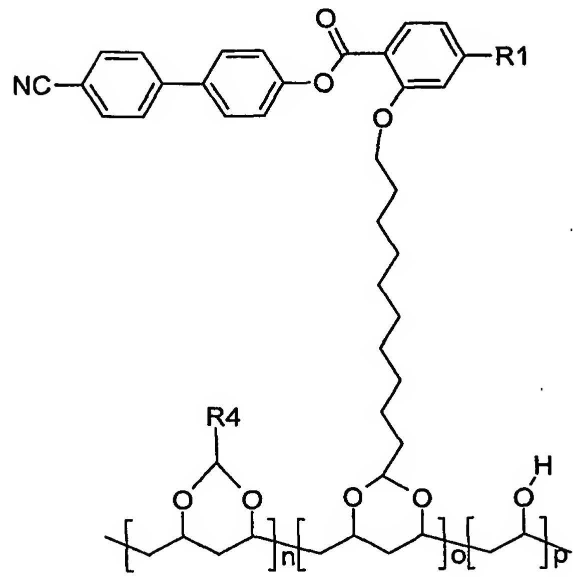
Formula LXIV



Formula LXV

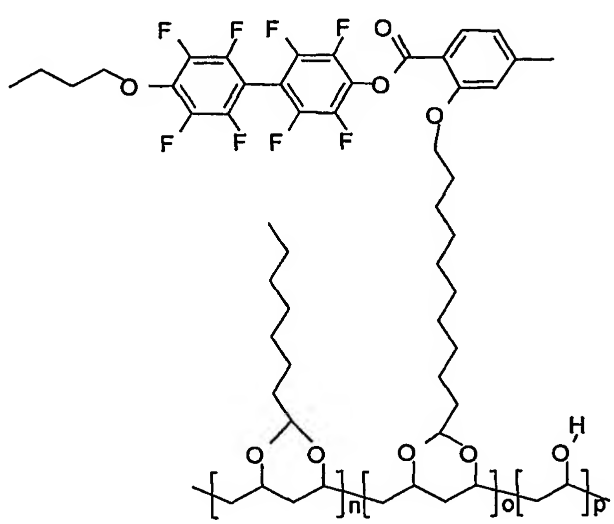


Formula LXVI



Formula LXVII

A specific example of this type of polymers suitable as surface-director alignment layer material in the above described embodiment is represented by Formula LXVIII.



Formula LXVIII

Instead of using a polymer, the side-chains of Formulas XLVI to LXVIII can be chemically attached, as known

to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

Examples of liquid crystal bulk layer materials having a negative dielectric anisotropy, and being suitable in the above described embodiment, are a mixture of MLC 6608 ($\Delta\varepsilon = -4.2$) and MBBA ($\Delta\varepsilon = -0.8$), a mixture of MLC 6884 ($\Delta\varepsilon = -5.0$) and MBBA ($\Delta\varepsilon = -0.8$), and a mixture of MDA 98-3099 ($\Delta\varepsilon = -6$) and MBBA ($\Delta\varepsilon = -0.8$), all of which are nematic liquid crystal materials supplied by Merck.

2. Same sign of dielectric anisotropy

In a second group of embodiments of the device according to the invention, the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies ($\Delta\varepsilon$) of same sign. Said device is preferably an in-plane switching liquid crystal device.

a) In-plane switching liquid crystal devices

In an in-plane switching liquid crystal device, according to said second group of embodiments of the invention, the orientation of the molecules of said bulk layer is directly controllable by an applied electric field to perform an in-plane switching of an initial first planar orientation to a field-induced second planar orientation, whereas an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on said substrates, termed projected surface-director, presents said preferred orientation in a geometrical plane in parallel with said substrate, termed preferred field-induced planar orientation.

In an in-plane switching device according to the invention, the electric field is applied in parallel with the confining substrates (i.e. along the liquid crystal bulk layer).

An embodiment of an in-plane switching liquid crystal device according to the invention is a device wherein

both the liquid crystal bulk and the surface-director alignment layers exhibit positive dielectric anisotropies ($\Delta\varepsilon > 0$), said surface-director alignment layers being applied on the inner surfaces of substrates confining the liquid crystal bulk layer.

The molecules (i.e. the side-chains) of the surface-director alignment layers have in this embodiment an initial planar orientation, in a first direction, in relation to the confining substrate surfaces, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules in the field-off state ($E = 0$). The surface-director alignment layers are preferably unidirectionally rubbed to obtain the preferred field-off first planar orientation direction.

The device may either comprise two surface-director alignment layers (two-sided embodiment) or alternatively only one surface-director alignment layer (one-sided embodiment).

When an external electric field is applied ($E \neq 0$) along the liquid crystal bulk layer (in parallel with the confining substrates) between electrodes, the liquid crystal bulk molecules will, due to their positive dielectric anisotropy, switch in-plane to a field-induced second planar orientation direction along the direction of the applied field. The molecules (i.e. the side-chains) of the surface-director alignment layers will, also switch in-plane to a field-induced second orientation direction due to their positive dielectric anisotropy when an electric field is applied along the layer and in parallel with the confining substrates. The in-plane switching molecules (i.e. the side-chains) of the surface-director alignment layers will thus promote a fast switching from the field-off first planar orientation direction of the liquid crystal bulk molecules to their field-induced second planar orientation direction. Thus, the switching of the liquid crystal bulk molecules to the field-induced orientation direction will in this

case be faster, at lower applied voltage, than the in-plane switching of a prior art liquid crystal device having a non-switching surface-director alignment layer (shown in Fig 3). In this context, it shall however be noted that the surface-director alignment layer(s) of this device according to the invention does not mediate the in-plane switching of the liquid crystal bulk molecules, which orientation is directly controllable via dielectric coupling. The surface-director alignment layer(s) does not drive but merely facilitates said in-plane bulk switching.

The liquid crystal bulk layer of the device according to said embodiment may have a positive dielectric anisotropy within the range of from 1 to 30, and the surface-director alignment layers may have a positive dielectric anisotropy within the range of from 1 to 30.

It is believed to be advantageous if the positive dielectric anisotropy of the surface-director alignment layers has a larger positive value (more positive), preferably much larger, than the positive dielectric anisotropy of the liquid crystal bulk layer.

Formulas XLVI to LXVIII are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described embodiment (an in-plane switching liquid crystal device). As previously described, these polymers comprise side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provides positive dielectric anisotropy.

Instead of using a polymer, the side-chains of Formulas XLVI to LXVIII can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

In an in-plane switching liquid crystal device, according to the invention, having a surface-director alignment layer and a liquid crystal bulk layer exhibiting dielectric anisotropies of same sign, it may be advantageous to use two electrode arrays 20, 21, each array consisting of two interdigitated electrodes 22, arranged so that the electric field obtainable within the first electrode array 20 is substantially perpendicular to the electric field obtainable within the second electrode array 21 (Fig 11). Each array 20,21 is applied on a confining substrate 23. In this embodiment both the switching and the relaxation of the liquid crystal bulk molecules occur in the presence of an applied electric field, and a short response time is easily attainable.

Another similar embodiment of an in-plane switching liquid crystal device according to the invention, is a device wherein both the liquid crystal bulk layer and the surface-director alignment layer(s) exhibit negative dielectric anisotropies ($\Delta\varepsilon < 0$).

When an external electric field ($E \neq 0$) is applied along the liquid crystal bulk layer (i.e. in parallel with the confining substrates), the liquid crystal bulk molecules will, due to their negative dielectric anisotropy, switch in-plane from a field-off first planar orientation direction to a field-induced second planar orientation direction perpendicular the direction of the applied electric field. The molecules (i.e. the side-chains) of the surface-director alignment layers will, also switch in-plane from a field-off first planar orientation direction to a field-induced second orientation direction due to their negative dielectric anisotropy when an electric field is applied along the layer(s) and in parallel with the confining substrates. The in-plane switching molecules (i.e. the side-chains) of the surface-director alignment layer(s) will thus promote a fast switching from the field-off first planar orientation direction of the liquid crystal bulk molecules to their

field-induced second planar orientation direction. Thus, the switching of the liquid crystal bulk molecules to the field-induced orientation direction will in this case be faster than the in-plane switching of a corresponding prior art liquid crystal device having a non-switching surface-director alignment layer. Also in this case, it shall be noted that the surface-director alignment layer of the device according to the invention does not mediate the in-plane switching of the liquid crystal bulk molecules, it merely facilitates said switching.

The liquid crystal bulk layer of the device according to this embodiment may have a negative dielectric anisotropy within the range of from -6 to -1, and the surface alignment layers may have a negative dielectric anisotropy within the range of from -6 to -1.

It is believed to be advantageous if the negative dielectric anisotropy of the surface-director alignment layers has a larger negative value (more negative), preferably much larger, than the negative dielectric anisotropy of the liquid crystal bulk layer.

Formulas XXXIII to XLV are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described embodiment (an in-plane switching liquid crystal device). As previously described, these polymers comprise side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide negative dielectric anisotropy.

Instead of using a polymer, the side-chains of Formulas XXXIII to XLV can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

Examples of liquid crystal bulk layer materials having a negative dielectric anisotropy, and being suitable

in the above described embodiment, are a mixture of MLC 6608 ($\Delta\varepsilon = -4.2$) and MBBA ($\Delta\varepsilon = -0.8$), a mixture of MLC 6884 ($\Delta\varepsilon = -5.0$) and MBBA ($\Delta\varepsilon = -0.8$), and a mixture of MDA 98-3099 ($\Delta\varepsilon = -6$) and MBBA ($\Delta\varepsilon = -0.8$), all of which are nematic liquid crystal materials supplied by Merck.

It shall be noted that the combination of a surface-director alignment layer and a liquid crystal bulk layer exhibiting dielectric anisotropies of same sign is also applicable and advantageous for out-of-plane switching liquid crystal devices (described below), even though the effect of a decreased rise time is more pronounced for in-plane switching liquid crystal devices. Thus, the device according to the invention wherein the liquid crystal bulk layer and the surface-director alignment layer exhibit dielectric anisotropies of same sign is preferably an in-plane switching liquid crystal.

b) Out-of-plane switching liquid crystal devices

In an out-of-plane switching liquid crystal device according to said second group of embodiments of the invention, the orientation of the molecules of said bulk layer is directly controllable by an applied electric field to perform an out-of-plane switching of an initial vertical orientation to a field-induced planar orientation, whereas an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on the confining substrates, termed projected surface-director, presents said preferred orientation in a geometrical plane in parallel with said substrates, termed preferred field-induced planar orientation.

In an out-of-plane switching liquid crystal device according to the invention, the electric field is applied normally to the confining substrates (i.e. normally to the liquid crystal bulk layer).

Fig 12 schematically shows part of an embodiment of an out-of-plane switching liquid crystal device 24 according to the invention, in the field-off state ($E = 0$), wherein both the surface-director alignment layers 25

(only one layer is shown) and the liquid crystal bulk 26 exhibit negative anisotropy ($\Delta\varepsilon < 0$), said surface-director alignment layers 25 being applied on the inner surfaces of substrates confining the liquid crystal bulk layer 26.

The molecules (i.e. the side-chains) of the surface-director alignment layers 25 have in this embodiment an initial vertical orientation in relation to the confining substrate surfaces, thus resulting in vertically or substantial vertically aligned liquid crystal bulk molecules 26 in the field-off state ($E = 0$), as shown in Fig 12. The surface-director alignment layers 25 are also preferably unidirectionally rubbed to obtain a preferred direction of a field-induced planar alignment of the liquid crystal bulk molecules 26.

The device may either comprise two surface-director alignment layers (two-sided embodiment) or alternatively only one surface-director alignment layer (one-sided embodiment).

When an external field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 26 between electrodes 27 on the inner surfaces of the confining substrates, the liquid crystal bulk molecules 25 will, due to their negative anisotropy, switch out-of-plane to a field-induced planar orientation defined by the rubbing direction.

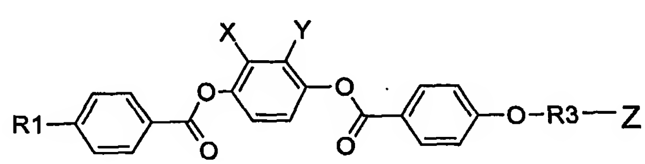
The molecules (i.e. the side-chains) of the surface-director alignment layers 25 will, due to their negative dielectric anisotropy, also switch out-of-plane to a field-induced planar orientation defined by the rubbing direction. The out-of-plane switching molecules (i.e. the side-chains) of the surface-director alignment layers 25 will thus promote a fast switching from the field-off vertical orientation of the liquid crystal bulk molecules 26 to the field-induced planar orientation. Thus, the switching of the liquid crystal bulk molecules 26 from the field-off vertical orientation to a field-induced planar one will be faster, at lower applied voltage, than

in the out-of-plane switching of a prior art liquid crystal device having non-switching surface-director alignment layers. It should, however, be noted that the surface-director alignment layers 25 of said device does not, according to the invention, mediate the out-of-plane switching of the liquid crystal bulk molecules 26, which orientation is directly controllable by the applied field via dielectric coupling. The surface-director alignment layers 25 merely facilitates said out-of-plane switching.

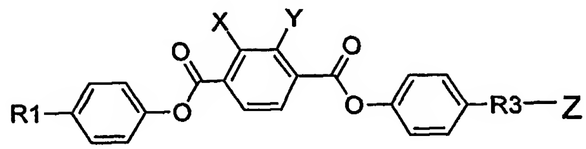
The liquid crystal bulk layer 26 of the device according to said embodiment may have a negative dielectric anisotropy within the range of -6 to -1, and the surface-director alignment layers 25, may have a negative dielectric anisotropy within the range of -6 to -1.

It is believed to be advantageous if the surface-director alignment layers 25 has a larger negative value (more negative), preferably much larger, than the negative dielectric anisotropy of the liquid crystal bulk 26.

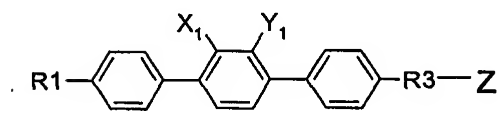
Formulas LXIX to LXXII are examples of surface-director alignment materials suitable for providing an initial field-off vertical alignment in the above described embodiment (an out-of-plane switching liquid crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provide negative dielectric anisotropy.



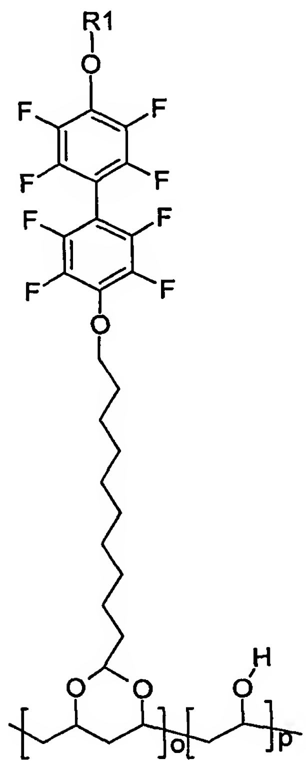
Formula LXIX



Formula LXX



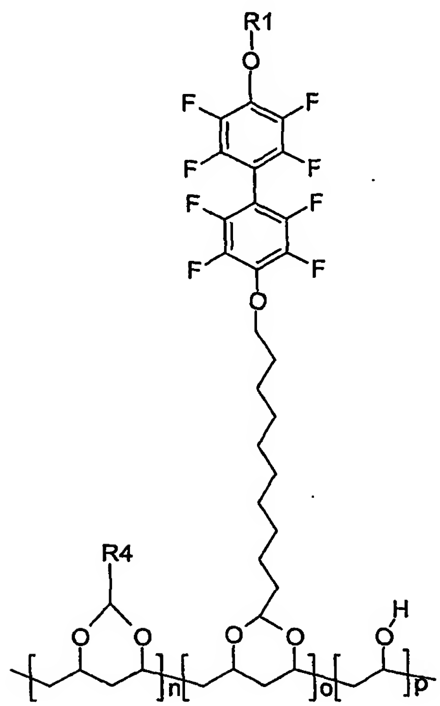
Formula LXXI



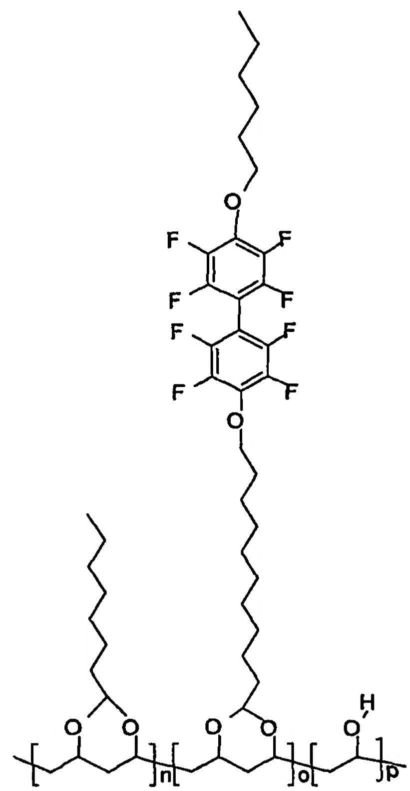
Formula LXXII

Formula LXXIII represents additional examples of surface-director alignment layer materials suitable for providing an initial field-off vertical alignment in the above described embodiment (an out-of-plane switching

liquid crystal device). These polymers comprises side-chains (S_1) exhibiting permanent and/or induced dipole moments that in ordered phase provide negative dielectric anisotropy and side-chains (S_3) exhibiting no permanent and/or induced dipole moments and thus providing no dielectric anisotropy.



Formula LXXIII



Formula LXXIV

A specific example of this type of polymers suitable as surface-director alignment layer material in the above described embodiment is represented by Formula LXXIV.

Instead of using a polymer, the side-chains of Formulas LXIX to LXXIV can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

In another similar embodiment of an out-of-plane switching liquid crystal device according to said second group of embodiments of the invention, the orientation of the molecules of said bulk layer is directly controllable by an applied electric field to perform out-of-plane switching of initial planar orientation to a field-induced vertical orientation, whereas an orthogonal projection of said surface-director (of the liquid crystal bulk layer) on a geometrical plane perpendicular to said substrates, termed projected surface-director, presents said preferred orientation termed preferred field-induced vertical orientation.

Fig 13 shows part of an embodiment of an out-of-plane switching liquid crystal device 28 according to the invention, in the field-off state ($E = 0$), wherein both the surface-director alignment layers 29 (only one layer is shown) and the liquid crystal bulk 30 exhibit positive anisotropy ($\Delta\varepsilon > 0$), said surface-director alignment layers 29 being applied on the inner surfaces of substrates confining the liquid crystal bulk layer 30.

The molecules (i.e. the side-chains) of the surface-director alignment layers 29 have in this embodiment an initial planar orientation in relation to the confining substrate surfaces, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules 30 in the field-off state ($E = 0$). The surface-director alignment layers 29 are also preferably unidirectionally rubbed to obtain a preferred direction of the field-off planar alignment of the liquid crystal bulk molecules 30.

The device may either comprise two surface-director alignment layers 29 (two-sided embodiment) or alternatively only one surface-director alignment layer 29 (one-sided embodiment).

When an external field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 30 between electrodes 31 on the inner surfaces of the confining substrates, the liquid crystal bulk molecules 30 will, due to their posi-

tive anisotropy, switch out-of-plane to a field-induced vertical orientation.

The molecules (i.e. the side-chains) of the surface-director alignment layers 29 will, due to their positive dielectric anisotropy, also switch out-of-plane to a field-induced vertical orientation when an electric field is applied normally to the confining substrates. The out-of-plane switching molecules (i.e. the side-chains) of the surface-director alignment layers 29 will thus promote a fast switching from the field-off planar orientation of the liquid crystal bulk molecules 30 to the field-induced vertical orientation. Thus, the switching of the liquid crystal bulk molecules 30 from the field-off planar orientation to a field-induced vertical one will be faster, at lower applied voltage, than in the out-of plane switching of a prior art liquid crystal device having a non-switching surface-director alignment layer. It should, however, be noted that the surface-director alignment layers 29 of the device according to the invention does not mediate the out-of-plane switching of the liquid crystal bulk molecules 30, which orientation is directly controllable by the applied field via dielectric coupling. The surface-director alignment layers 29 merely facilitates said out-of-plane switching.

The liquid crystal bulk layer 30 of the device according to said embodiment may have a positive dielectric anisotropy within the range of 1 to 30, and the surface-director alignment layers 29 may have a positive dielectric anisotropy within the range of 1 to 30.

It is believed to be advantageous if the positive dielectric anisotropy of the surface-director alignment layers 29 has a larger positive value (more positive), preferably much larger, than the positive dielectric anisotropy of the liquid crystal bulk 30.

Formulas XLVI to LXVIII are examples of surface-director alignment materials suitable for providing an initial field-off planar alignment in the above described

embodiment (an out-of-plane switching liquid crystal device). As previously described, these polymers comprise side-chains exhibiting permanent and/or induced dipole moments that in ordered phase provides positive dielectric anisotropy.

Instead of using a polymer, the side-chains of Formulas XLVI to LXVIII can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer in the device according to the invention.

Variants of the hitherto described first and second group of embodiments of the device according to the invention, are devices comprising two surface-director alignment layers exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs. This type of devices is believed to provide a short total response time, in particular a short decay time for an out-of-plane switching liquid crystal device.

Fig 14 illustrates part of an embodiment of an out-of-plane switching liquid crystal device 32 according to the invention, wherein asymmetric (in view of dielectric anisotropy) surface-director alignment layers 33,34 are applied on the inner surfaces of substrates confining a liquid crystal bulk layer 35. The liquid crystal bulk 35 exhibits a negative dielectric anisotropy ($\Delta\varepsilon < 0$) and the first surface-director alignment layer 33 exhibits a negative dielectric anisotropy ($\Delta\varepsilon < 0$) and the second surface-director alignment layer 34 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$).

The molecules (i.e. the side-chains) of the surface-director alignment layers 33,34 have in this embodiment an initial vertical orientation in relation to the confining substrate surfaces, thus resulting in vertically or substantially vertically aligned liquid crystal bulk molecules 35 in the field-off state ($E = 0$), as shown in

Fig 14a. The surface-director alignment layers 33,34 are also preferably unidirectionally rubbed to obtain a preferred orientation of a field-induced planar alignment of the liquid crystal bulk molecules 35.

When an external electric field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 35 between electrodes 36 on the confining substrates, a bent deformation in the liquid crystal bulk layer 35 is induced, as shown in Fig 14b, thus giving rise to a flexoelectric polarization P_{fl}. The applied electric field couples to the flexoelectric polarization and, depending on the polarity of the applied electric field, the bent deformation will increase or decrease, thus giving rise to a linear electro-optic response.

Fig 15 illustrates part of an embodiment of an out-of-plane switching liquid crystal device 37 according to the invention, wherein asymmetric (in view of dielectric anisotropy) surface-director alignment layers 38,39 are applied on the inner surfaces of substrates confining a liquid crystal bulk layer 40. The liquid crystal bulk 40 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$) and the first surface-director alignment layer 38 exhibits a positive dielectric anisotropy ($\Delta\varepsilon > 0$) and the second surface-director alignment layer 39 exhibits a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

The molecules (i.e. the side-chains) of the surface-director alignment layers 38,39 have in this embodiment an initial planar orientation in relation to the confining substrate surfaces, thus resulting in planar or substantially planar aligned liquid crystal bulk molecules 40 in the field-off state ($E = 0$), as shown in Fig 15a. The surface-director alignment layers 38,39 are also preferably unidirectionally rubbed to obtain a preferred orientation of the field-off planar alignment of the liquid crystal bulk molecules 40.

When an external electric field is applied ($E \neq 0$) normally to the liquid crystal bulk layer 40 between

electrodes 41 on the confining substrates, a splay deformation in the liquid crystal bulk layer 40 is induced, as shown in Fig 15b, thus giving rise to a flexoelectric polarization P_{fl}. The applied electric field couples to the flexoelectric polarization and, depending on the polarity of the applied electric field, the splay deformation will increase or decrease, thus giving rise to a linear electro-optic response.

3. Structural parts of the surface-director alignment layers exhibiting opposite signs of dielectric anisotropy

In a third group of embodiments of the device according to the invention, the surface-director alignment layer(s) comprise(s) structural parts exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs. This type of device is believed to provide a short decay time as well as a short rise time, both for an in-plane switching liquid crystal device and an out-of-plane switching liquid crystal device.

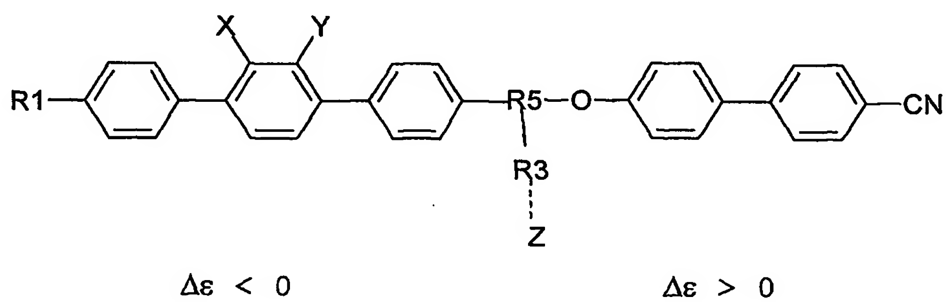
It is believed that said structural parts exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs preferably should be homogeneously distributed in the surface-director alignment layer.

The device according to this third group of embodiments may either comprise two surface-director alignment layers (two-sided embodiment) or alternatively only one surface-director alignment layer (one-sided embodiment).

A surface-director alignment layer comprising structural parts exhibiting dielectric anisotropies ($\Delta\varepsilon$) of opposite signs is obtainable using, for instance, materials comprising dimeric chemical structures having a first structural part of positive dielectric anisotropy ($\Delta\varepsilon > 0$) and a second structural part of negative dielectric anisotropy ($\Delta\varepsilon < 0$).

Formula LXXV represents examples of surface-director alignment layer materials suitable for providing an initial field-off planar alignment in the above described embodiment (an out-of-plane or in-plane switching liquid

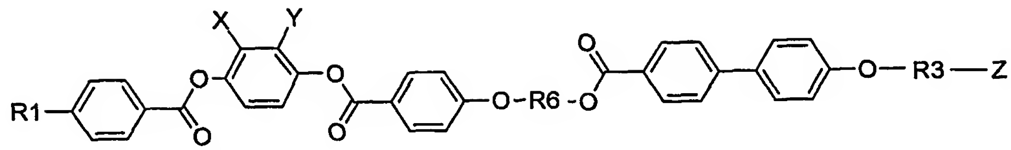
crystal device). These polymers comprise side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains having dimeric structures, each one comprising a first structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides positive dielectric anisotropy and a second structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides negative dielectric anisotropy



Formula LXXV

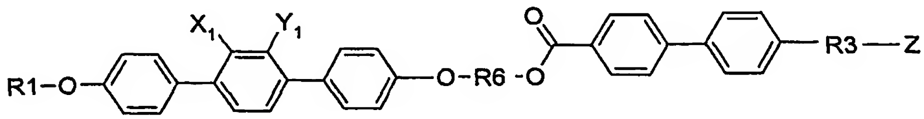
Instead of using a polymer, the side-chains of Formula LXXV can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer.

Formulas LXXVI to LXXX are examples of surface-director alignment layer materials suitable for providing an initial field-off vertical alignment in an out-of-plane switching liquid crystal device according to the above described embodiment. These polymers comprises side-chains (S_1) chemically bound to a polymer main chain (Z), said side-chains having dimeric structures, each one comprising a first structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides positive dielectric anisotropy of and a second structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides negative dielectric anisotropy



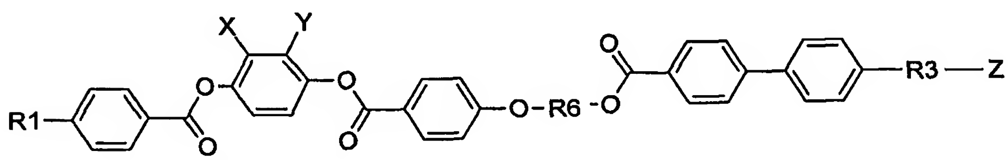
$\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXVI



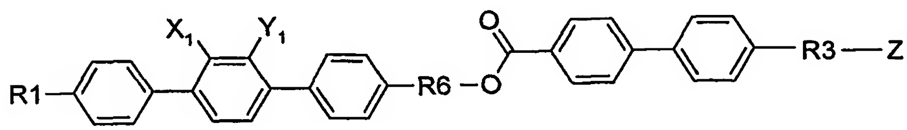
$\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXVII



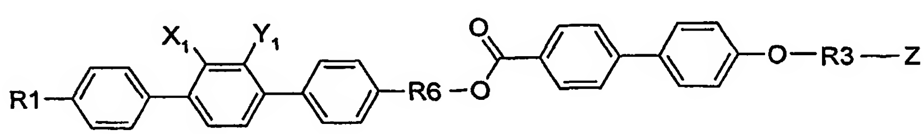
$\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXVIII



$\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXIX



$\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXX

Instead of using a polymer, the side-chains of Formulas LXXVI to LXXX can be chemically attached, as known to persons skilled in the art, to a solid surface, such

as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer.

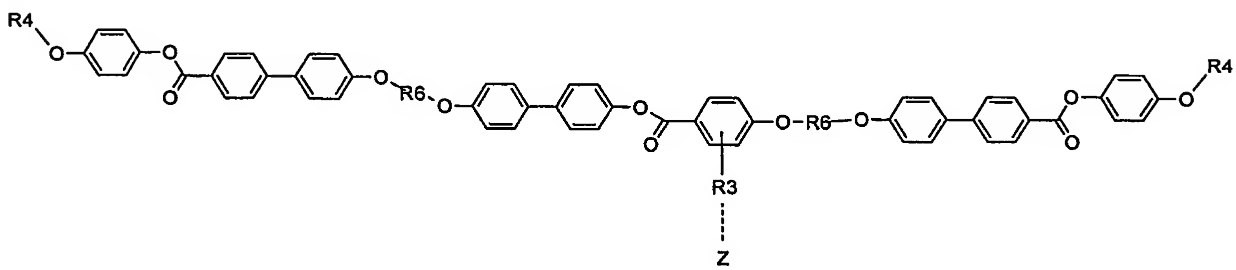
Fig 16 illustrates part of an embodiment of an out-of-plane switching liquid crystal device 42 according to the invention having an initial field-off vertical orientation and comprising surface-director alignment layers (only one layer is shown), applied on substrate surfaces 43, having a dimeric structure comprising a first structural part 44 of positive dielectric anisotropy ($\Delta\varepsilon > 0$) and a second structural part 45 of negative dielectric anisotropy ($\Delta\varepsilon < 0$). The liquid crystal bulk layer 46 has a negative dielectric anisotropy ($\Delta\varepsilon < 0$).

Fig 16a illustrates the field-off state ($E = 0$) and Fig 16b illustrates the field-induced state ($E \neq 0$).

Materials comprising trimeric chemical structures having a first structural part of positive dielectric anisotropy ($\Delta\varepsilon > 0$), a second structural part of negative dielectric anisotropy ($\Delta\varepsilon < 0$), and a third structural part of negative ($\Delta\varepsilon < 0$) or positive ($\Delta\varepsilon > 0$) dielectric anisotropy may also be useful in this third group of embodiments of the invention. The third structural part may be similar or different as compared to the first and second structural parts. Thus, chemical structures comprising two or more structural parts, wherein each structural part exhibits a positive or negative dielectric anisotropy and two of said three structural parts exhibit dielectric anisotropies of opposite signs, may be useful in a device according to this third group of embodiments according to the invention.

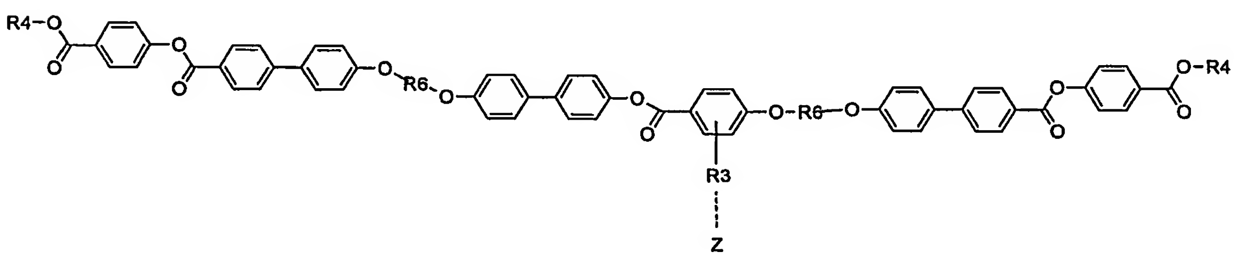
Formulas LXXXI to LXXXIII are examples of surface-director alignment layer materials suitable for providing an initial field-off planar alignment in the above described embodiment (an out-of-plane or an in-plane switching liquid crystal device). These polymers comprises side-chains (S_1) chemically attached to a polymer main chain (Z), said side-chains having trimeric struc-

tures, each one comprising a first structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides positive dielectric anisotropy ($\Delta\varepsilon > 0$), a second structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides negative dielectric anisotropy negative dielectric anisotropy ($\Delta\varepsilon < 0$), and a third structural part exhibiting a permanent and/or induced dipole moment that in ordered phase provides either negative ($\Delta\varepsilon < 0$) or positive ($\Delta\varepsilon > 0$) dielectric anisotropy.



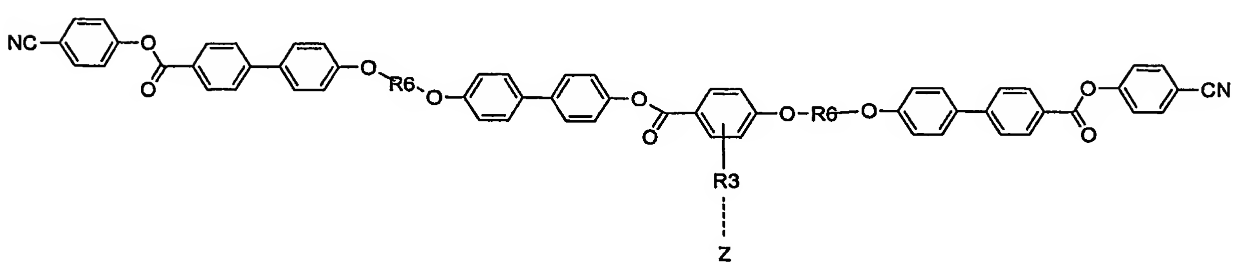
$\Delta\varepsilon > 0$ $\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXXI



$\Delta\varepsilon > 0$ $\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXXII



$\Delta\varepsilon > 0$ $\Delta\varepsilon < 0$ $\Delta\varepsilon > 0$

Formula LXXXIII

Instead of using a polymer, the side-chains of Formulas LXXXI to LXXXIII can be chemically attached, as known to persons skilled in the art, to a solid surface, such as a gold surface, a silicon dioxide surface or a glass surface comprising silanol groups, to form a suitable material for use as the surface-director alignment layer.

Fig 17 illustrates part of an embodiment of an out-of-plane switching liquid crystal device 47 according to the invention having an initial field-off planar orientation and comprising surface-director alignment layers (only one layer is shown), applied on substrate surfaces 48, having a trimeric structure comprising a first structural part 49 of positive dielectric anisotropy ($\Delta\varepsilon > 0$), a second structural part 50 of negative dielectric anisotropy ($\Delta\varepsilon < 0$), and a third structural part 51 of positive dielectric anisotropy ($\Delta\varepsilon > 0$). The liquid crystal bulk layer 52 has a positive dielectric anisotropy ($\Delta\varepsilon > 0$).

Fig 17a illustrates the field-off state ($E = 0$) and Fig 17b illustrates the field-induced state ($E \neq 0$).

Examples

A liquid crystal display glass substrate having a thickness of 1.10 mm was used. One side of the substrate was provided with an indium tin oxide (ITO) layer (electrode material) having a surface resistance of 80 Ω/cm^2. Addressing electrode structures were provided using a conventional photolithography process known to persons skilled in the art. The glass substrate was cut into pieces with a size of 9,5 X 12,5 mm, and the edges were ground. Also glass substrates of the size 25.4 x 25.4 mm have been used.

The substrates were then washed several times in distilled water in an ultra-sonic bath, dried and then washed two times in isopropanol. The substrates were thereafter moved into a clean-room.

The ITO side of the substrates was spin coated with a surface-director alignment layer material, dissolved in tetrahydrofuran (THF) to a concentration of about 0.1% w/w (concentrations up to 0.5% w/w have been tested). The speed was 3000-4000 rpm and coating was performed during 30 seconds.

After coating, the substrates were heated for approximately 5-10 minutes at a temperature of 125°C to remove the solvent (THF) and form an alignment layer. Drying can be performed in an oven or on a hot plate and/or under vacuum. Then the substrates were thereafter set to cool down.

It shall be noted that also two-step processes comprising heating for about 5-10 minutes at 60°C followed by heating for about 10-30 minutes at 130° have been tested with acceptable results. However, it may be noted that temperatures over room temperature are in principle not necessary for the drying step.

The applied surface-director alignment layer, on top of the ITO layer, was buffed with a nylon cloth using a drum diameter of 120 mm, a drum speed of 300 rpm, a linear speed of 15 mm/sec, and a pile contact length of about 0.5 mm. All substrates were buffed in the same direction.

Two substrates, one substrate being rotated 180° to make the buffing direction antiparallel in the cell, were thereafter put together to a cell using UV-glue (Norland NOA68), and spacers in a string at two of the edges. An alternative is to spray spacers from an ethanol dispersion onto the cell surface. The cell was put under pressure in a UV-exposure box for 15 minutes.Small electric cords were ultra-sonically soldered to each ITO-surface of the cell.

A nematic liquid crystal, in isotropic phase, was then introduced into the cell by means of capillary forces (this can be done with or without vacuum applied).

It shall be noted that the device described above is of a relatively simple type. Devices can be of much larger size and can be addressed in different ways, such as by using a passive matrix-addressed type or an active matrix-addressed type. In these cases, steps involving complex microelectronics productions steps are involved.In all examples below, the solvents were dried before use thereof by passing the reaction solvents through a short chromatography column containing ICN Alumina N super 1 from ICN Biomedicals GmbH Germany.

In all the examples below, standard reactions well-known to a person skilled in the art were used for the preparation of the polymers.

The maximum degree of functionalisation in the examples below is, due to statistical reasons 86 %. Hence, a minimum of 14 % of the initial hydroxyl groups remain after completion of the reaction.

<u>Example 1</u>: *Out-of-plane switching liquid crystal device having an electrically stabilised vertically aligned surface-director alignment layer*

<u>Preparation of surface-director alignment layer material</u>

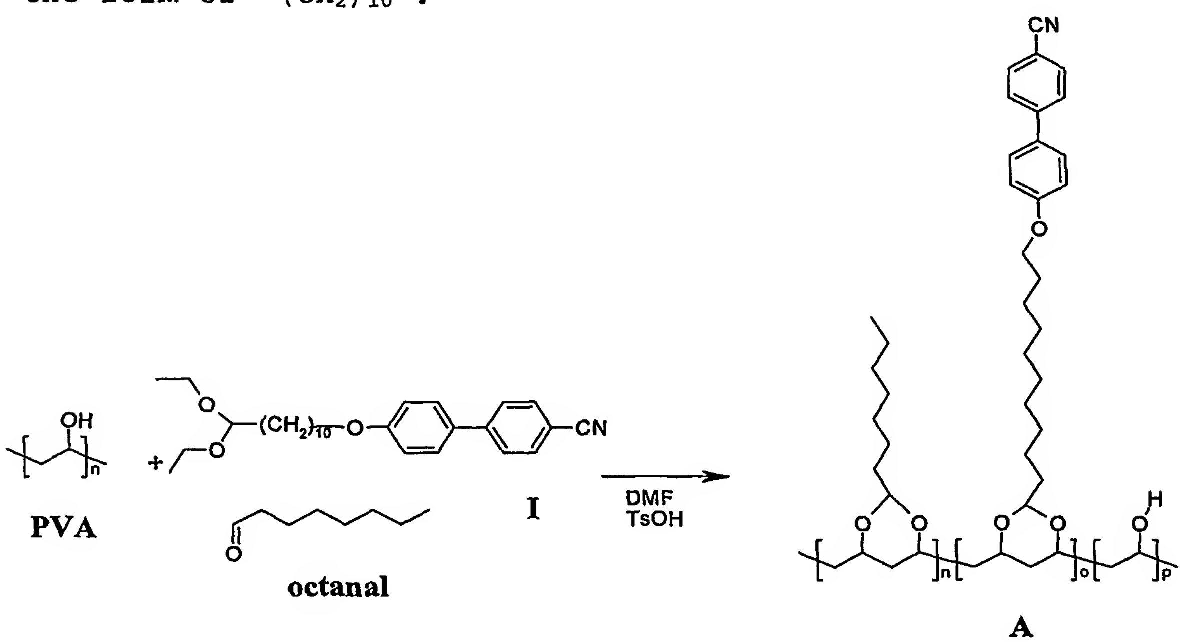
In a 100 ml flask, 0.70 g of 4′-(11,11-diethoxy-undecyloxy)-biphenyl-4-carbonitrile (side-chain precursor I) (see D Lacey et al, Macromolecular Chemistry and Physics 200, 1222-1231 (1999)), 0.081 g of octanal, 0.198 g of polyvinyl alcohol (PVA) (number average molecular weight of about 15 000 g/mol), and 0.10 g of p-toluenesulfonic acid (TsOH) were dissolved in 20 ml of dry N,N-dimethylformamide (DMF) and stirred at about 55°C for 24 hours.

The reaction mixture was then poured into 150 ml of methanol and a polymer was precipitated. The precipitate was collected and dissolved in 5 ml of chloroform and re-precipitated in 100 ml of methanol. The re-precipitation was repeated twice.

The yield was 0.29 g of polymer (i.e. 40% calculated on the amount of added polyvinyl alcohol). Losses were due to the presence of low molar mass polymer that was removed in the workup procedure (i.e. the precipitation procedure).

^{1}H-NMR spectrum of the obtained polymer was in accordance with structure A of Scheme I. The side-chain molar ratio I/octanal in the polymer as determined using NMR was found to be 2/1 (= o/n in structure A). Furthermore, (o+n)/p was found to be about 42/16.

The side-chain formed from side-chain precursor I is attached to the polymeric backbone via spacing atoms in the form of $-(CH_2)_{10}-$.



Scheme I

Manufacturing of a liquid crystal device according to the invention

The ITO side of the substrates was coated, as described above, with polymer A (= Formula XIX) prepared as described above. It shall be noted, however, that any one of the structures according to Formulas I to XXXII may be used in this embodiment.

The polymer layer (about 100 nm) was rubbed unidirectionally very lightly to induce a small pre-tilt of the mesogenic side-chains of the polymer, and the cell was thereafter assembled.

The sandwich cell (cell gap about 3 μm) was then filled with the nematic mixture MBBA/MLC6608 (Merck, Germany), 40/60 wt%, MBBA exhibiting $\Delta\varepsilon = -0.8$ and MLC 6608 exhibiting $\Delta\varepsilon = -4.2$.

In this cell, the polymer layer acts as a surface-director alignment layer.

The alignment of the cell after cooling to room temperature was inspected by means of a polarising microscope and it was found to be uniform vertical.

The response rise and decay times were measured in a set-up comprising a polarising microscope, a photodetector, an oscilloscope and a puls-generator.

The electro-optic response of the cell with vertical alignment, under application of unipolar impulses with low frequency (about 1 Hz), is depicted in Fig 18. At a voltage (U) of 9.2 V, the measured rise and decay time were about 1.9 and 3.8 ms, respectively. Thus, the measured decay time is about 5 times shorter than the decay time usually measured in out-of-plane switching liquid crystal cells with an initial vertical alignment.

<u>Example 2</u>: *Out-of-plane switching liquid crystal device having an electrically stabilised vertically aligned surface-director alignment layer*

Example 1 was repeated except that the sandwich cell was filled with the nematic mixture MBBA/MLC6884 (Merck, Germany), 40/60 wt%, MLC 6884 exhibiting $\Delta\varepsilon = -5.0$ and MBBA exhibiting $\Delta\varepsilon = -0.8$.

At a voltage (U) of 6.1 V, the measured rise and decay time were about 2.5 and 1.8 ms, respectively, as shown in Fig 19.

Example 3: *Out-of-plane switching liquid crystal device having an electrically stabilised vertically aligned surface-director alignment layer*

Preparation of surface-director alignment layer material

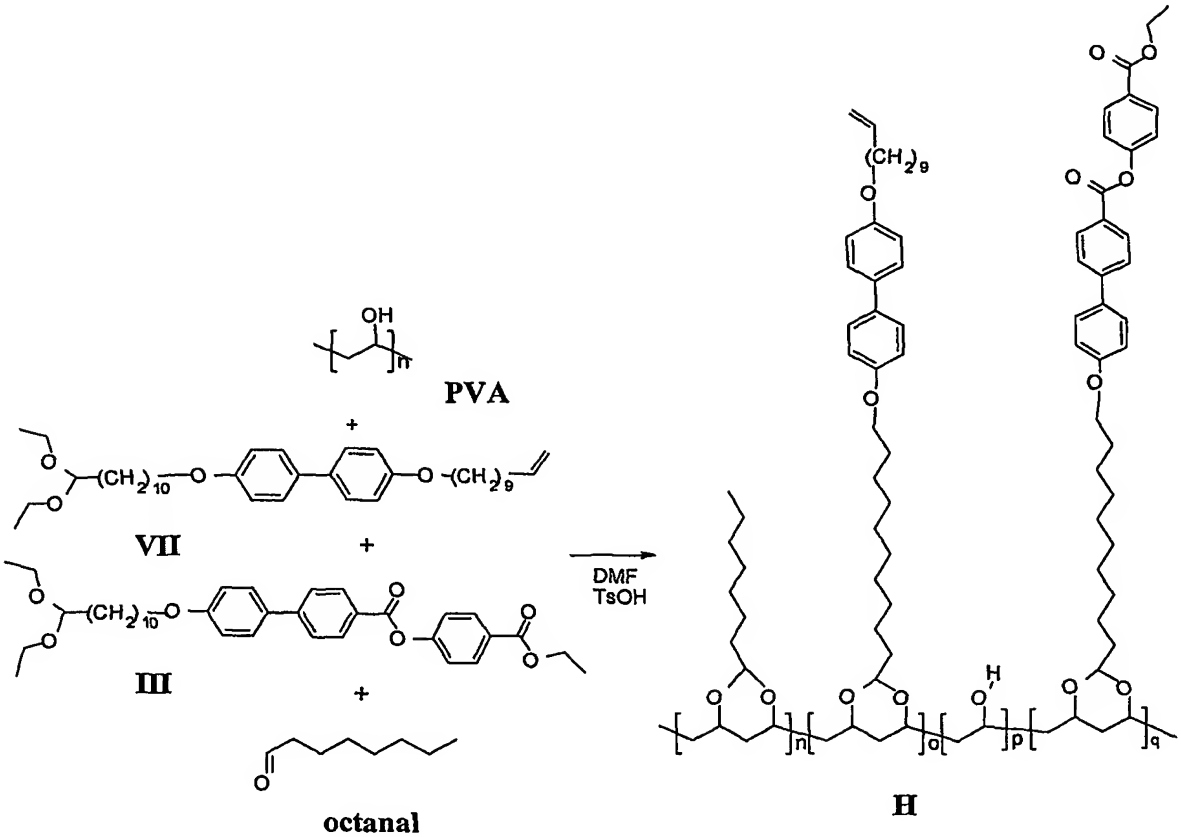
In a 100 ml flask, 0.11 g of 4′-(11,11-diethoxy-undecyloxy)-biphenyl-4-carboxylic acid 4-ethoxycarbonyl-phenyl ester (side-chain precursor III), 0.07 g of 4′-(11,11-diethoxy-undecyloxy)-4′-undec-10-enyloxy-biphenyl (side-chain precursor VII), 0.018 g of octanal, 0.037 g of PVA (number average molecular weight of about 15 000 g/mol), and 0.03 g of TsOH, were dissolved in 10 ml of dry DMF and stirred at about 55°C for 48 hours.

The reaction mixture was then poured into 150 ml of methanol and a polymer was precipitated. The precipitate was collected and dissolved in 5 ml of chloroform and re-precipitated in 100 ml of methanol. The re-precipitation was repeated twice.

The yield was 0.09 g of polymer. Losses were due to the presence of low molar mass polymer that was removed in the workup procedure.

^{1}H-NMR spectrum of the obtained polymer was in accordance with structure H of Scheme II.

The side-chain formed from side-chain precursor III is attached to the polymeric backbone via spacing atoms in the form of $-(CH_2)_{10}-$ and the side-chain formed from side-chain precursor VII is attached to the polymeric backbone via spacing atoms in the form of $-(CH_2)_{10}-$.



Scheme II

Manufacturing of a liquid crystal device according to the invention

Example 1 was repeated except that the ITO side of the substrates was coated, as described above, with polymer H (= Formula XXXII) prepared as described above. The polymer layer was, however, not rubbed. Furthermore, the sandwich cell was filled with the nematic material MLC6884 (Merck, Germany) exhibiting $\Delta\varepsilon = -5.0$.

At a voltage (U) of 5.2 V, the measured rise and decay time were about 2.7 and 2.7 ms, respectively, as shown in Fig 20.

Example 4: *Out-of-plane switching liquid crystal device having an electrically stabilised planar aligned surface-director alignment layer*

Preparation of surface-director alignment layer material

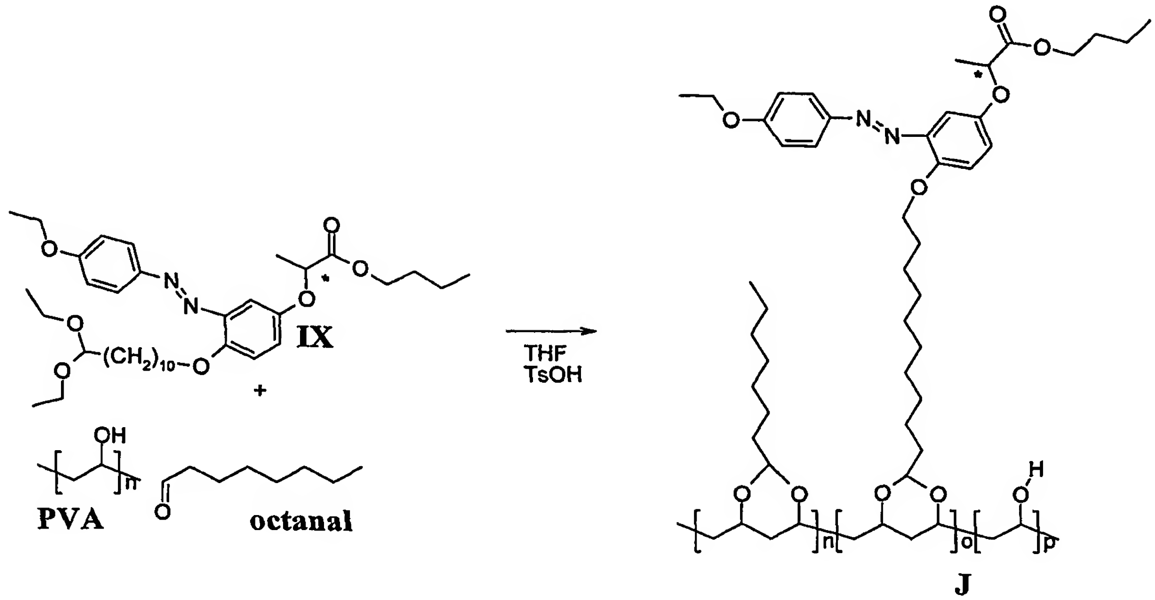
In a 100 ml flask, 1.0 g of 2-[4-(11,11-diethoxy-undecyloxy)-3-(4-ethoxy-phenylazo)-phenoxy]-propionic acid butyl ester (side-chain precursor IX), 0.205 g of octanal, 0,25 g of PVA (number average molecular weight of about 15 000 g/mol), and 0.1 g of TsOH were dissolved in 25 ml of dry THF and stirred at about 60°C for 24 hours.

The reaction mixture was then poured into 250 ml of methanol and a polymer was precipitated. The precipitate was collected and dissolved in 5 ml of chloroform and re-precipitated in 100 ml of methanol. The re-precipitation was repeated twice.

The yield was 0.56 g of polymer. Losses were due to the presence of low molar mass polymer that was removed in the workup procedure.

^{1}H-NMR spectrum of the obtained polymer was in accordance with structure J of Scheme III. The side-chain molar ratio IX/octanal in the polymer as determined using NMR was found to be 1/1 (= o/n in structure J). Furthermore, (o+n)/p was found to be about 43/18.

The side-chain formed from side-chain precursor IX is attached to the polymeric backbone via spacing atoms in the form of $-(CH_2)_{10}-$.



Scheme XIII

<u>Manufacturing of a liquid crystal device according to the invention</u>

The ITO side of the substrates was coated, as described above, with polymer J (= Formula XLIV) prepared as described above. It shall be noted, however, that any one of the structures according to Formulas XXXIII to XLV may be used in this embodiment.

The polymer layer (about 100 nm) was rubbed unidirectionally to ensure uniform planar alignment of the mesogenic side-chains of the polymer, and the cell was thereafter assembled.

The sandwich cell (cell gap about 3 μm) was then filled with the nematic mixture E7 (BDH/Merck) exhibiting $\Delta\varepsilon > 0$.

In this cell, the polymer layer acts as a surface-director alignment layer.

The alignment of the cell after cooling to room temperature was inspected by means of a polarising microscope and it was found to be uniform planar.

The rise and decay times were measured in a set-up comprising a polarising microscope, a photo-detector, an oscilloscope and a puls-generator.

The electro-optic response of the cell with planar alignment, under application of unipolar impulses with low frequency (about 1 Hz), was found to be about 0.5 ms and 4 ms for rise and decay times, respectively.

Example 5: *Out-of-plane switching liquid crystal device having an electrically stabilised planar aligned surface-director alignment layer*

Example 4 was repeated except that the sandwich cell was filled with the nematic material E70 A (BDH/Merck) exhibiting $\Delta\varepsilon = +10.8$.

At a voltage (U) of 5.6 V, the measured rise and decay time were about 1.1 and 1.6 ms, respectively, as shown in Fig 21.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent for one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.